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Williams Research Corp, Walled Lake, Mich

Prepared for

Environmental Protection Agency, Ann Arbor, Mich Div of Advanced Automotive Power Systems Development

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AUTOMOTIVE GAS TURBINE ECONOMIC ANALYSIS

Investment Cast Turbine Wheel Supplement

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The study provides adequate evidence that volume production of automotive turbine wheels investment cast in nickel base alloys is both feasible nd within the current state of the art. The study has generated a logical process .or mass producing investment cast turbine wheels and also provides the necessary capitalization requirement to support such a manufacturing capability. The cost analysis supports the original premise of an 80%-20% material to labor ratio. In addition the capitalization, manloading and resultant overhead considerations are well within automobile industry standards. The O.E.M. selling price per turbine wheel mass produced at the projected study levels would be approximately $10.04 to $12.15 each dependent on alloy selection. The capitalization of a facility to investment cast 2,000,000 turbine wheels per year would cost approximately $12,000,000 to $15,000,000, dependent on alloy selection.

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AUTOMOTIVE GAS TURBINE ECONOMIC ANALYSIS

Investment Cast Turbine Wheel Supplement

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July 1973

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SUPPLEMENT

AUTOMOTIVE GAS TURBINE

ECONOMIC ANALYSIS

INVESTMENT CAST TURBINE WHEEL

ENVIRONMENTAL PROTECTION AGENCY

ADVANCED AUTOMOTIVE POWER SYSTEMS DEVELOPMENT DIVISION

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FOREWORD

THIS REPORT, NO. WR-ER11, REVISION NO. 1 ENTITLED "SUPPLEMENT, AUTOMOTIVE GAS TURBINE ECONOMIC ANALYSIS, INVESTMENT CAST TURBINE WHEEL" IS SUBMITTED TO THE ENVIRONMENTAL PROTECTION AGENCY, DIVISION OF ADVANCED AUTOMOTIVE POWER SYSTEMS DEVELOPMENT. THE REPORT IS SUBMITTED PURSUANT TO CONTRACT NO. 68-01-0405 BETWEEN THAT AGENCY AND WILLIAMS RESEARCH CORPORATION AND IS BASED ON ALL WORK ACCOMPLISHED UNDER THAT CONTRACT.

R. T. Hall
Project Director

E. E. Davenport
Director of Administration

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	2
GENERAL PROCESS DESCRIPTION	4
Manufacturing Assumptions	5
Investment Patterns	6
Shell Molding	7
Refractory Mold Burnout, Assembly and Firing	9
Master Ingot Melting	10
Production Melting and Casting	11
Cooling, Shakeout and Cleaning	14
Finishing Operations	16
COST SUMMARY	17
Raw Materials	18
Metal Production Costs - IN713LC	18
Shell Cost Summary	20
Plant and Equipment	25
Manpower Requirement	25
Turbine Wheel Cost	45
OPTIONAL ALLOY IN-738 SUPPLEMENT	47
Optional Heat Treating	48
ACKNOWLEDGMENTS	53
ADDENDUM 1 - AUTOMATED INVESTMENT CASTING IN THE USSR	54
ADDENDUM 2 - ALLOY SUMMARIES, 713LC/IN-738	59

SUMMARY

1. This study provides adequate evidence that volume production of automotive turbine wheels investment cast in nickel base alloys is both feasible and within the current state of the art.

2. This study has generated a logical process for mass producing investment cast turbine wheels and also provides the necessary capitalization requirement to support such a manufacturing capability.

3. The cost analysis supports the original premise of an 80%-20% material to labor ratio. In addition the capitalization, manloading and resultant overhead considerations are well within automobile industry standards.

4. The F.P.M. selling price per turbine wheel mass produced at the projected study levels would be approximately $10.04 to $12.15 each dependent on alloy selection.

5. The capitalization of a facility to investment cast 2,000,000 turbine wheels per year would cost approximately $12,000,000 to $15,000,000, dependent on alloy selection.

SECTION I

INTRODUCTION

The Automotive Gas Turbine Economic Analysis Final Report, dated December 1972, used an existing prototype automotive turbine engine as a baseline. This engine was analyzed in detail for its producibility, utilizing value analysis techniques to further refine the engine for mass production. Manufacturing processes were studied for their applicability to turbine engine components, and a development program was outlined to foster process development for those areas defined as high cost items.

One high cost area identified was that of investment castings used in the automotive turbine engine. A specific area of concern was the cost of investment turbine wheels after vendor prices were obtained for production rates of 1,000,000 castings per year. These vendor prices indicated an unreasonable proportion of labor cost to material cost.

Based on the material content of the turbine wheels, an Automotive Original Equipment Manufacturer (OEM) selling price of $14.00 each was developed. Some comments ensued regarding the assumptions made to arrive at this price; and in response to these comments, the Environmental Protection Agency authorized a more detailed analysis of the cost of investment castings produced in automotive quantities.

Although current prices for investment castings in the United States might indicate that precision parts made by this method have no place in the automotive sector, it should be noted that investment castings are used extensively for automotive applications in Europe. Specific attention is directed to the highly automated Gorky Automotive Works, an investment foundry in Russia, which produces approximately 15,000,000 castings per year for the industry. (See addendum #1 for details.)

A detailed description of the Gorky Operation was furnished by Technology Associates, Inc. of Dedham, Mass.; and an evaluation of these data definitely indicates that high-volume, automated investment foundries can produce certain types of investment castings at low cost. In addition, there has been progress in the United States on the part of several material suppliers to develop binder processes that will reduce the time required to build investment shell molds. A typical process; developed by the E.I.duPont Company, trade name Colal; elimates the necessity of drying the shell between dips.

After considering these binder developments and the advanced automation techniques of the Gorky Foundry, it has been concluded that the investment casting process may, in fact, offer the best solution to the problem of manufacturing turbine wheels at a cost acceptable to the automotive industry.

For purposes of this study, a conceptual investment casting process, suitable for volume production of automotive turbine wheels, has been developed. This process includes the physical and cost elements of a production facility, equipment, manpower, raw material, and all other significant manufacturing elements necessary to develop a meaningful unit cost for automotive turbine wheels. This supplement to the original report presents the details of this process and the associated cost analysis.

GENERAL PROCESS DESCRIPTION

The proposed investment casting process is based on fundamental investment casting expertise utilizing, where applicable, developments in fast drying binders, typical high volume production automation and some modestly innovative production melting techniques to produce low cost turbine wheels.

The pattern materials are polystyrene or polystyrene/wax utilized in multi wheel assemblies. The shell making is accomplished in an automated continuous slurry/stucco dip system using a binder system which precludes long intermediate drying cycles during the building steps.

Melting is carried out in two steps; the first to alloy master heat ingots, and the second to accomplish production melting for the final casting operation. Some innovations, as described

in the detailed process, develop practical solutions for shell support during the pouring operation to accommodate heat retention and withstand the forces applied to the shell resulting from the proposed centrifugal assist.

The finishing operations such as cleaning, inspection, cutting, and heat treatment, use either current or modifications of current production techniques.

For purposes of identification the following detail process description is broken down into the basic manufacturing techniques. These are:

Investment Pattern making
Shell making
Master heat melting
Production melting
Cooling, shakeout, and cleaning
Cutting, final inspection and shipping

In addition, the processing includes an optional heat treat operation to support alloy IN738.

Manufacturing Assumptions

1. The refractory mold technique utilizes binder systems which do not require intermediate drying between refractory layers.

2. The melting operations are carried out in two stages. The first to produce ingot and the second the production casting. Direct melting costs are $0.03/pound for ingot and $0.05/pound for the production melt.
3. The system is designed to eliminate labor where practical by use of automatic production techniques.
4. The production foundry will operate 250 days, two 8-hour shifts, 5 days per week. Additional maintenance is planned for furnace overhaul and system maintenance. The primary master ingot furnace and any heat treating facilities will operate 250 days, three 8-hour shifts, 5 days per week.
5. Direct labor rates are assumed to be $7.50/hr., including fringes.
6. Capital depreciation on all facilities except building at 12 years. Building carried 20 years.
7. General and administrative costs at 10 percent.
8. Corporate profit at 25 percent.

Investment Patterns

The first step of the detailed process concerns itself with the manufacture of the subassembly patterns which in final assembly will be used for building the refractory shell.

The material/s are polystyrene and/or polystyrene wax combinations. All parts are made using high production rate injection molding equipment.

The turbine wheel pattern is injection molded in one piece polystyrene using a movable segment water cooled mold. These machines are fully automatic and in sufficient quantity to produce in excess of 640 turbine wheel patterns per hour.

The balance of the assembly such as the central runner, pouring cup patterns etc. are molded separately. For a visual presentation of the pattern assembly see Figure 1.

After molding, the separate patterns are conveyed to an assembly area where the components will be assembled manually using the appropriate patterns and hooked to an overhead conveyor which carries the assemblies to the shell molding area.

Shell Molding

The shell molding area consists of handling systems, slurry tanks, stuccoing beds and drying areas designed to produce 110-125 mold assemblies per hour in an automated assembly line. Supporting equipment consists of batch slurry preparation and storage tanks, and refractory preparation, separation, reconditioning and storage equipment.

The investment pattern assemblies are delivered to the shell building area. This area must be humidity and temperature controlled.

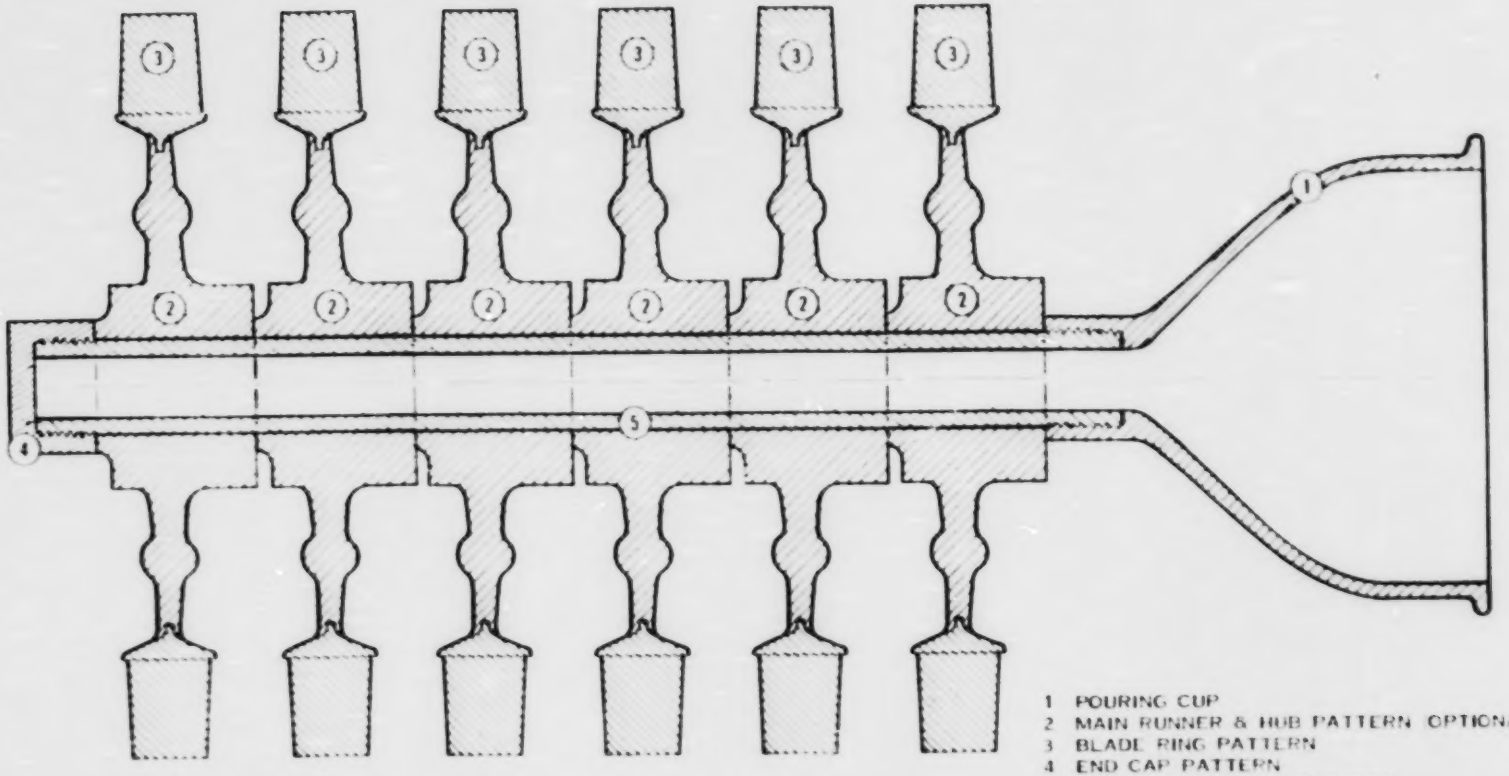


FIGURE 1

TURBINE WHEEL PATTERN ASSEMBLY

The assemblies are then dipped in a refractory slurry, retracted and dipped in a fluidized bed of stuccoing sand. The slurry coat is repeated and then alternately dipped and stuccoed in the binder slurries until three to six coats are built up.

After the final dip, the shell/pattern assemblies are carried into a drying room and dried for approximately 15 hours. The drying parameters will consist of temperature, humidity, and air flow control.

After the drying cycle is complete the refractory molds are conveyed to the next operation which is pattern burnout.

Refractory Mold Burnout, Assembly and Firing

The shell/pattern assemblies are transferred from the drying room to the burnout/firing furnace. This furnace is used to burnout the polystyrene, fire the shell and preheat for pouring.

Prior to firing, the shells are placed in ceramic canisters (silicon nitride or similar) and supported with coarse refractory invested between the canister and the shell. This assembly is then placed on the furnace conveyor and fired to achieve the desired temperature for pouring and to assure that all pattern residue is removed.

These assemblies are then conveyed hot to the production furnace line for pouring.

Master Ingot Melting

The turbine wheel alloy is melted from virgin or reverted material or a combination of same.

The master heat is considered a separate entity on off-line operation. This is done to allow total independence from the production line and conversely the production line is not directly dependent on the conversion furnace. The ingots are stockpiled to allow a reasonable amount of downtime for furnace repair and production melting lead.

The melting procedure involves charging, melting, alloy adjustment and ingot pouring in a vacuum furnace.

The master heat total is 12,000-15,000 pounds and the daily production requirement is 35,000 pounds plus.

The furnace charge is made up in an adjacent charge room. All materials are dry stored. The charge bucket is transferred to the vacuum furnace and the charge is then laid in the crucible in preparation for melting.

The ingot molds are assembled at the pouring station within the vacuum chamber.

The vacuum chamber is sealed and the operating vacuum is established. The furnace temperature can be elevated during pumpdown.

When the charge is molten, final alloy adjustments are made using material already placed in a separate additive vacuum lock. Spectrographic samples are tested for alloy balance and when all percentages are nominal, the furnace may be poured.

The complete heat is poured into ingot molds and allowed to solidify.

After solidification is achieved, the vacuum chamber is opened and the molds are removed to a stripping (teardown) area.

The ingots are removed from the molds, cropped and cut into production furnace charges of approximately 24 pounds each and stored until needed.

An illustration of a typical ingot furnace may be found in Figure 2.

Production Melting and Casting

The production melting line consists eight 50-pound capacity electric induction vacuum furnaces (including two spares). These furnaces are able to pour every 180 seconds. They are complete with three handling locks, one to charge the furnace,

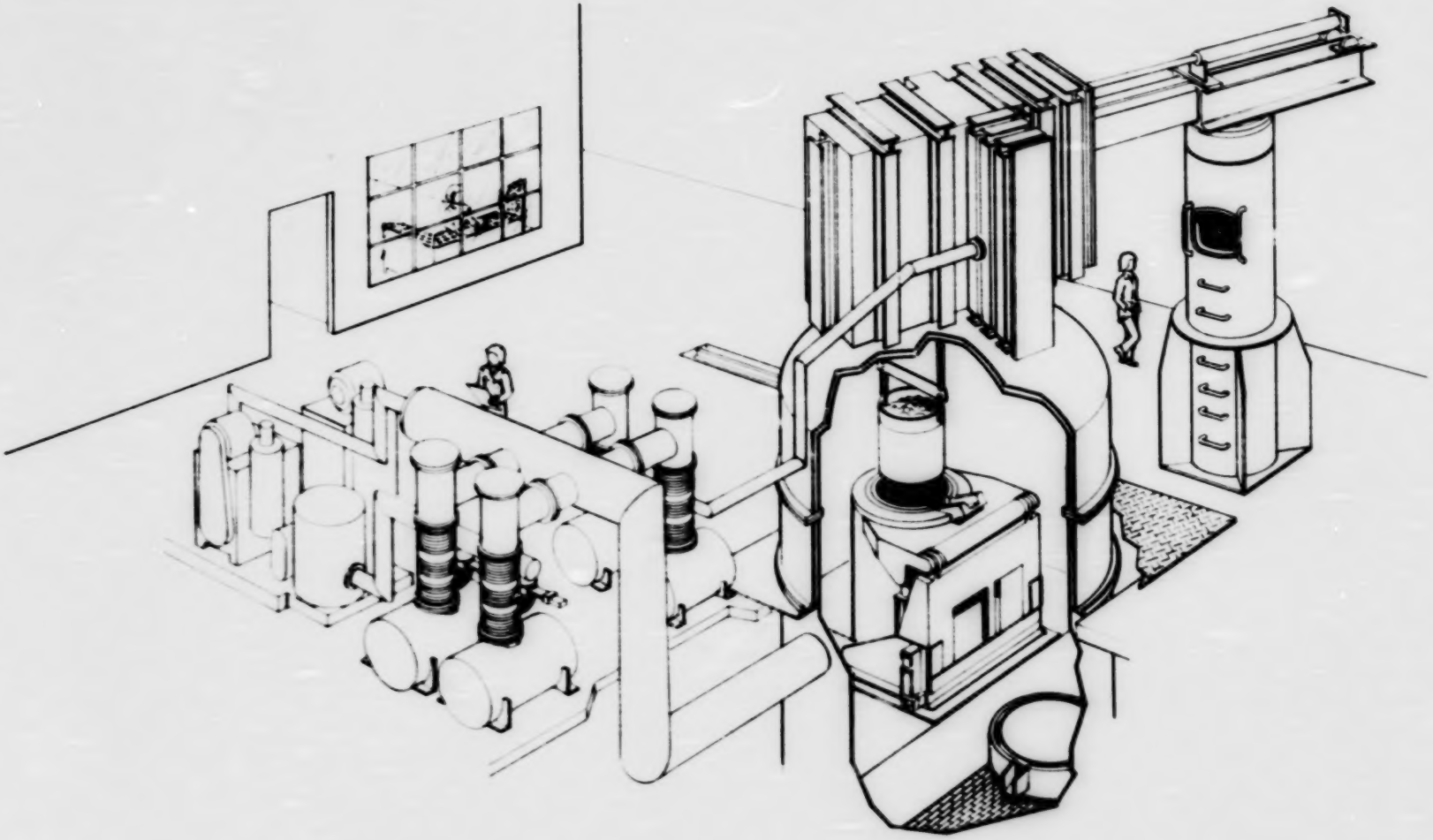


FIGURE 2

MASTER HEAT INGOT FURNACE

the second to place the mold assembly into the pouring station and the third to remove the casting from the furnace chamber. Self-contained manipulators, to move the shell and casting in the vacuum chamber from and to the entry and exit locks after vacuum is achieved, are included. Centrifugal assist is incorporated in the pouring table. In addition, there are mechanical manipulators at the entry and exit locks and appropriate conveyors to deliver the assemblies to the separation and shakeout equipment.

The pre-cut ingot charges are placed in a feed hopper or magazine which releases a single billet charge which is transferred into an induction coil. The charge is preheated in the induction coil to approximately 2250°F in atmosphere. When temperature is achieved, the billet is moved from the induction coil through the outer door of the charging lock. The outer door is closed, the lock pumped down and the charge pushed from the lock into the backtilted furnace crucible.

After the furnace crucible is returned to the vertical position the preheated charge is brought to superheat temperature (approximately 2650°F). During this heating cycle the previous casting (assembly) is locked out of the furnace through the exit lock and a new shell/canister assembly is placed on the pouring table.

When the charge is at the proper superheat temperature, the pouring sequence is initiated by tilting the furnace and actuating the centrifugal drive. After pouring, the centrifugal drive is continued until the exit lock is ready for the next charging sequence (approximately 2 to 2-1/2 minutes).

See Figure 3 for furnace example.

Cooling, Shakeout and Cleaning

The cooling and shakeout portion of the production facility consists of conveyors to remove all castings from the exit locks of the production furnaces, an assembly separation station and a shell/casting separation unit. The shell material is returned to the refractory preparation area to be crushed, ground and separated for reuse. The ceramic canisters are returned to the canister preheater for reuse.

The casting assembly is mechanically positioned in the vacuum furnace exit lock when the pouring sequence is complete. The interlock door is closed and the vacuum is released. When the outer exit lock door is open a mechanical manipulator extracts the assembly and places it on a conveyor which carries it to the assembly separation station.

At the separation station an extractor removes the casting from the loose refactory/canister and places it on an overhead conveyor. At the same time an arm dumps the coarse refractory out

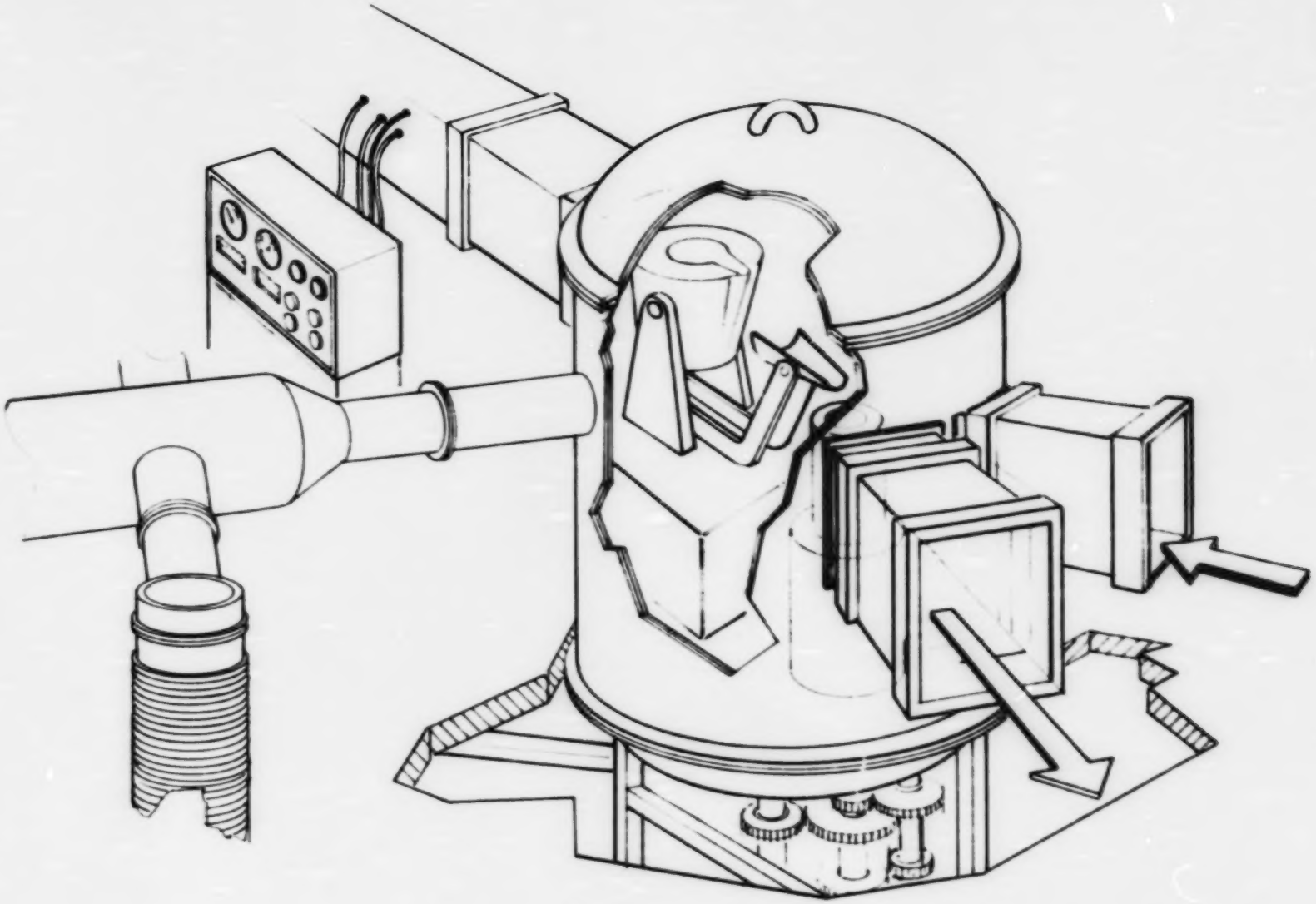


FIGURE 3

PRODUCTION MELTING FURNACE

of the canister. The refractory is collected mechanically and it and the canister are returned to the shell/canister assembly station for reuse.

The casting is moved to the cooling/shakeout unit where the shell is completely removed by vibration and high pressure water jets.

The castings are carried to the cleaning unit by overhead conveyor. The refractory shell material is recovered in coarse slurry form and is returned to the shell refractory recycling unit.

The proposed recycling system consists of the appropriate drying, crushing and screening equipment to process and grade the fused silica for reuse. Some loss is anticipated and a summary of final yield may be seen on Page 24 of this report.

The cleaning operation consists of light etching and hot water rinsing the castings and is a continuation of the shakeout production line.

Finishing Operations

The castings are conveyed to a line of cutoff machines which should be designed to automatically restrain, index and cut off (by friction saws) the individual turbine wheels from the as-cast stack. The wheels drop on a soft conveyor and are sep-

arated from the sprue which is returned to the charge room for remelt. The turbine wheels are dimensionally checked by an automatic gaging system.

After inspection, the wheels are packaged, using individual containers.

COST SUMMARY

The turbine wheel production level which established this cost analysis is two million units per year. This being based on two wheels per engine and the original economic analysis based on a production commitment of one million engines per year.

The Foundry operation to produce this quantity of wheels is based on 250 operating days and two 8-hour shifts. The exception to this is the ingot furnace which would operate on a three shift basis. This will produce a minimum of 630 wheels per hour including an estimated 5% scrap.

To evaluate costs the following primary cost centers were developed:

1. Raw Materials
2. Plant & Equipment Capitalization
3. Manpower (Direct Labor)
4. Overhead, Administrative Fees and Profit

Within each of those cost centers detailed breakdowns are shown and appropriate tables are referenced as applicable.

Raw Materials

The first primary cost center which was considered is the cost of raw materials; the various metallic constituents making up the ingot charge, the refractory system for shells including binder and wax/plastic pattern material.

Metal Production Costs - IN713LC

Nickel base alloy IN-713LC was used for pricing in the original automotive turbine engine study. This alloy is currently used in the prototype engine.

The casting characteristics of the alloy support the primary considerations of the manufacturing processes previously described.

The cost of the alloy is evaluated using the sum total of the required constituents of the alloy in forms that are compatible with normal vacuum melting practices. A summary of the constituents, charge form and costs is found on Table I. The nominal current price per pound is $1.61. In addition $0.05/pound was added for melting cost at the ingot furnace. A summary of annual ingot costs may be found on Table II.

TABLE I

MASTER HEAT-VIRGIN MATERIAL COST - IN713 LC

ELEMENT	%	FORM	COST/LB. ($)	WT./TON (LB.)	COST/TON ($)
C	0.05	Powder	0.50	1.0	0.50
Cr	12.50	Electrolytic	1.15	250.0	287.50
Ni	74.00	Electrolytic	1.53	1480.0	2260.00
Mo	4.20	Pellet	3.70	84.0	310.80
Cb/Ta	2.20	Cb/Ta	6.63	44.0	291.72
Ti	0.80	Sheet Scrap Sponge	1.37	16.0	21.92
Al	6.10	Pig	0.28	122.0	34.16
B	0.01	Ni/B	3.25	0.2	0.65
Zr	0.10	Sponge	3.52	2.0	7.04
				1999.2	3218.69

Price Per Lb. = $\frac{\$3218.69}{1999.2 \text{ lb.}}$ = \$1.61 lb.

= \$1.61 lb.

Included in the above costs were the following manufacturing assumptions:

1. Scrap - 5%

   Sprue Returns - 30%

2. Total Metal Loss

Cutting Loss	3%
Oxidation, Vaporization	5%
Spillage	2%

3. The per pound melting cost of $0.05/pound includes electrical power, coolant water, crucible repair and replacement and mold repair and replacement.

Using these assumptions the annual ingot production is shown on Table II and the final cost is $1.89 per pound which includes the primary ingot melting factor of $0.03/pound.

Shell Cost Summary

The shell building process was slightly more complex to analyze. The wax plastic system worked out to cost $.03 per wheel or about $0.01 per pound of metal and this is used for the purpose of pricing in this analysis.

To develop the amount of binder/refractory which would be used per pound of casting the following assumptions were made:
Volume of a typical (6) wheel stack investment shell:

TABLE II

ANNUAL INGOT PRODUCTION-COST SUMMARY

ALLOY IN713LC

Description	Wgt/Annual/lbs.	Melt Cost/lb.	Metal Cost/lb.	Annual Cost Total
Required Delivered Product	5,400,000	$0.03	$1.61	$8,856,000.00
Revert Metal	1,890,000	0.08*	Transfer	151,200.00
Total Metal Loss	727,000	0.03	1.61	1,192,280.00
Virgin Metal	6,127,000	0.03	1.61	10,048,280.00
		ANNUAL INGOT COST-POUND		
Required Wgt.	5,400,000		$1.89**	$10,199,480.00

* Includes Reprocessing Cost + Melt Cost

** Includes Average Cost of Delivered Product, Revert Metal and Total Metal Loss Replacement

The wheel O.D. is approximately 5", and the irregular form measures 27.5" long. By assuming a ⅛" thick shell buildup the volumetric relationship of the simple cylinder is:

$$\Delta_0 = \Delta_1 \times L = \text{Volume}$$

Where $\Delta_0 = 25.97\ m^2$

and $\Delta_1 = 21.65\ in^2$

and $L = 27.5"$

The volume therefore is $129.6\ in^3$.

If this volume is then considered as essentially dry fused silica (after drying) at a density of 100 lb/ft^3 or 0.0507 lb/in^3 the weight of cylinder $\Delta_0 - \Delta_1 \times L = 6.57$ lb. This weight of formed refractory shell is sufficient to produce a 22-23 pound turbine wheel assembly.

The constituents of the shell system less the pattern material were then developed in portional weights as follows:

Proportional Weight of Slurries (Est.):

2 Prime Coats M-1	0.57 Lbs.
3 Backup Coats M-2	3.00 lbs.
3 Backup Coats P-2	3.00 lbs.
Total Weight	6.57 lbs.

Thus the price breakdown of the entire refractory system is as follows:

Price Breakdown by Weight:

Colal M-1

25 lbs. Colal M @ .23/lb.	= $ 5.750
17.7 lbs. H_2O @ .001/lb.	= 0.020
.02 lbs. Antarox BL240	= 0.006
100 lbs. Fused Silica @ .18/lb.	= 18.000
Dry Shell per CWT	= $23.776
Or	= $ .238/lb.

Colal M-2

32 lbs. of Colal M @ .23/lb.	= $ 7.36
100 lbs. of Fused Silica @ .18/lb.	= 18.00
Dry Shell per CWT	= $25.36
Or	= $ 0.254/lb.

Colal P-2

35 lbs. of Colal P @ .36/lb.	= $12.60
100 lbs. of Fused Silica @ .18/lb.	= 18.00
Dry Shell per CWT	= $30.60
or	= $ .306/lb.

Gross Shell Cost:

0.57 lbs. M-1 @ $0.238/lb. =	$0.136
3.00 lbs. M-2 @ $0.254/lb. =	0.762
3.00 lbs. P-2 @ $0.306/lb. =	0.918
Gross Total	$1.816

The manufacturing process is developed to recover part of the refractory used in the shells and the following assumptions were used:

1. The solids composed of various mesh sizes of fused silica can be recovered at $0.005/lb. plus capitalization expense.

2. The recovery percentage will be 90% minus 5% operational loss or a net recovery of 85% of all fused silica used in the process.

A shell with a dry weight of 6.57 lbs. with 85% net recovery and a $0.005/lb. processing cost will be:

	6.57 lbs.
x	$ .18
	$1.183
less 15%	0.175
	$1.008
Less $.005/lb.	0.033
Process	$0.975 net recovery

By subtracting the net recovery from the gross refractory cost per shell the following refractory cost is developed.

Gross Material Cost:

	$1.816
Net Recovery Return	0.975
Net Mat'l. Cost Per Shell	$0.841

Cost Per Turbine Wheel:

$0.841 : 6 = $0.14

Cost Per lb. of Cast Metal (Useable)

Wheel = 2.7 lbs. $ .0506/lb.

Finally for storage requirements the following monthly inventory will be required: Annual use/cost relationships may be found in Table III.

Binders	95,190 Pounds
Silica (Fused)	170,000 Pounds
Wetting Agent	3,350 Pounds

Plant & Equipment

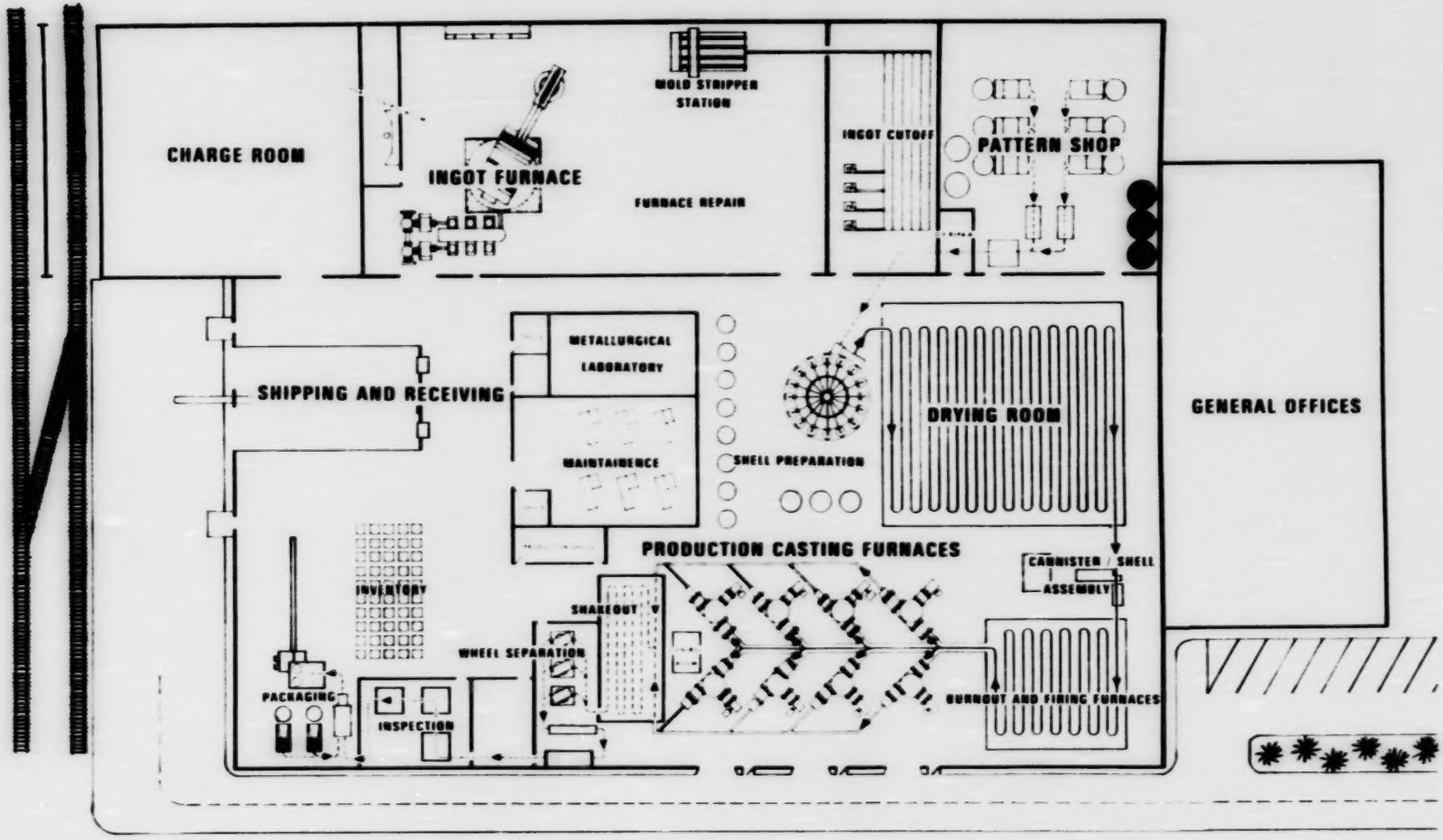
The second major cost center to discuss is plant and equipment capitalization.

The plant was laid out in rudimentary form (Figure 4), and then basic pricing was applied on a blanket basis per Mid-western area construction and approximate land costs (Table III Page 40).

The equipment called out in the facilities Summary Sheets (Table III, Page 27 thru 40) are based on supplier information. However, portions of the transfer systems were estimated by Williams Research Corporation Facilities Engineering. A grand total of facilities may be found on Table III Page 27.

Manpower Requirement

The third primary cost center is the manpower requirement. Using the operating assumptions, the manpower allocations are broken down by shift operations, and three categories of labor; direct hourly, indirect hourly and salary. These individual analyses are shown on Table IV, Pages 41 thru 44.



TURBINE WHEEL FOUNDRY

FIGURE 4

TABLE III

SUMMARY

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
A	Pattern Making - Plastic				$ 823,500	
B	Shell Making				1,180,000	
C	Dewax, Firing/Preheat Area				559,000	
D	Ingot Melt Facility				1,823,000	
E	Production Melting & Casting Facility				2,185,000	
F	Cooling, Shakeout & Cleaning				384,000	
G	Finishing Facility				1,386,000	
H	Shipping				169,500	
I	Maintenance				55,000	
J	Laboratories				355,000	
K	Miscellaneous				105,000	
L	Building & Grounds				2,304,000	
				Sub Total	$11,329,000	
				15% Engr. & Cont.	1,699,350	
					$13,028,350	
M	Heat Treat Alloy In-738			Incl 15% Engr. & Cont.	2,473,075	
				GRAND TOTAL (INCLUDING HEAT TREAT OPTION)	$15,501,425	

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
A	Pattern Making - Plastic					
A-1	Plastic Injection Mold Machines	8	$30,000	$7,500	$300,000	40 KVA 100 HP
A-2	Plastic Storage & Delivery System	1	17,500	8,000	25,000	5 HP
A-3	Soft Conveyor	100 Ft. @ 75	7,500		7,500	15 HP
A-4	Blade/Ring Dies (Molds)	8	50,000		400,000	50 HP
A-5	Nut & Pouring Cup - Dies/Molds	3	10,000		30,000	
A-6	Room Atmosphere		30,000	4,000	34,000	30 HP
A-7	Die Repair, Etc. (incl. B sec.)	1	15,000		15,000	50 HP
A-8	Ass'y Tube		12,000		12,000	
					$823,500	

* Incl. Installation

TABLE III (cont'd.) TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
B	Shell Making					
B-1	Refractory Reconditioning	1	$250,000	$35,000	$285,000	250 H.P.
B-2	Batch Slurry Make-up System		40,000	20,000	60,000	50 H.P.
B-3	Production Slurry Tanks		70,000	30,000	100,000	100 H.P.
B-4	Drying Room Conveyor		100,000	40,000	140,000	50 H.P.
B-5	Dip Manipulator Machines	16	25,000	60,000	460,000	160 H.P.
B-6	Binder Storage		75,000		75,000	75 H.P.
B-7	Drying Facility		50,000	10,000	60,000	50 H.P.
					$1,180,000	

* Incl. Installation

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
C	Dewax, Firing/Preheat Area					
C-5	Firing & Preheat System		$175,000	$40,000	$205,000	50 H.P.
C-6	Cannister Preheat		75,000	7,000	82,000	25 H.P.
C-7	Backup Sand Preheat		60,000	7,000	67,000	25 H.P.
C-8	Shell/Cannister Backup Sand Assembly Unit		50,000	15,000	65,000	15 H.P.
C-9	Cannister Manipulator		30,000	5,000	35,000	10 H.P.
C-10	Master Operator Console		75,000	30,000	105,000	5 H.P.
					$559,000	

Incl. Installation

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
D	Ingot Melt Facility					
D-1	12,000 - 15,000 Ingot Melt Furnace Including Vacuum System		$1,100,000	$100,000	$1,200,000	1200 KVA 500 KVA*
D-2	Mold Stripping Station		50,000	30,000	80,000	50 H.P.
D-3	Crucible Assembly		50,000	20,000	70,000	
D-4	20-Ton Crane		125,000	40,000	165,000	35 H.P.
D-5	Charge System		80,000	40,000	120,000	100 H.P.
D-6	Cutoff & Cropping Machines	4	10,000	2,000	48,000	40 H.P.
D-7	Walking Beam Table (Ingot transfer)		30,000	10,000	40,000	15 H.P.
D-8	Ingot Molds & Misc. Equip		100,000		100,000	
					$1,823,000	

* 1200 KVA Main Power; 500 KVA Auxiliary Equipment

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
E	Production Melting & Casting Facility					
E-1	Induction Vacuum Furnaces (50-lb.)	8	$125,000 ea.	$20,000 ea.	$1,160,000	1440 KVA*
E-2	Preheat Induction Coils	6	25,000 ea.	30,000	180,000	300 KVA
E-3	Master Control Room		250,000	50,000	300,000	20 H.P.
E-4	10-Ton Overhead Crane		95,000	15,000	110,000	25 H.P.
E-5	Inject. & Extract. Cannister Assembly Manipulators	12	25,000 ea.	5,000	360,000	180 H.P.
E-6	Hopper/Magazine (6) & Charging Devices		60,000	15,000	75,000	30 H.P.
					$2,185,000	

* Includes power and auxiliary equipment

TABLE III (cont'd.) TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
F	Cooling, Shakeout & Cleaning Facility					
F-1	Cooling Tunnel		$ 40,000	$12,000	$ 52,000	25 H.P.
F-2	Dumping Manipulator		35,000	10,000	45,000	15 H.P.
F-3	Cannister Return System		30,000	10,000	40,000	10 H.P.
F-4	Sand Return System		20,000	12,000	32,000	20 H.P.
F-5	Shakeout & Water Jet System		100,000	40,000	140,000	50 H.P.
F-6	Cleaning System		60,000	15,000	75,000	50 H.P.
					$384,000	

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
G	Finishing Facility					
G-1	Cutoff Units	4	$ 50,000 ea.	$12,000	$212,000	120 H.P.
G-2	Cleaning System		50,000	14,000	64,000	25 H.P.
G-3	Final Inspection Station		950,000	75,000	1,025,000	5 H.P.
G-4	Automatic Packaging Unit		75,000	10,000	85,000	25 H.P.
					$1,386,000	

TABLE III (cont'd.) TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
H	Shipping					
H-1	Container Packaging Unit		$25,000	$10,000	$ 35,000	10 H.P.
H-2	Platform Scales	2	5,000 ea.	2,000	12,000	
H-3	Lift Truck	2	8,000	--	16,000	
H-4	Levelators	2	12,000	7,500	31,500	
H-5	5-Ton Overhead Crane		75,000	--	75,000	10 H.P.
					$169,500	

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
I	Maintenance					
I-1	Miscellaneous Equipment		$50,000	$5,000	$55,000	250 HP
					$55,000	

TABLE III (cont'd.) TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
J	Laboratories					50 H.P.
J-1	Sand		$ 30,000	--	$ 30,000	
J-2	Slurry		40,000	--	40.000	
J-3	Metallurgical		275,000	$10,000	,000	
					$355,000	

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
K	Miscellaneous					
K-1	Offices & Furniture		$60,000		$60,000	
K-2	Cafeteria		25,000		25,000	
K-3	Shop Offices		20,000		20,000	
					$105,000	

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
L	Building & Grounds					
L-1	Building	60,000 ft^2			$2,104,000	
L-2	Land	10 Acres			100,000	
L-3	Parking, Misc. Grounds				100,000	
				Total	$2,304,000	

TABLE III (cont'd.)

TURBINE WHEEL FOUNDRY

ESTIMATED COST OF FACILITIES

TO HEAT TREAT IN-738 ALLOY

Item	Description & Reference	Unit	Est. Cost	Foundations & Erection	Est. Cost Total	Elec. HP or KVA
M	Heat Treatment Facility					
M-1	Four 3-Chamber Vacuum Batch Furnaces		$190,000	$35,000	$ 900,000	400 KVA
M-2	Four Continuous Exothermic Furnaces		150,000	35,000	440,000	350 KVA 100 H.P.
M-3	One 5-Ton Overhead Crane		75,000	Comp.	75,000	10 H.P.
M-4	Miscellaneous Cold Conveyor 50 ft.		2,500	1,000	3,500	10 H.P.
M-5	Miscellaneous Hot Conveyor 100 ft.		10,000	2,000	12,000	10 H.P.
M-6	Building	20,000 ft^2			700,000	
M-7	Grounds	2.0 Acres			20,000	
				Sub Total	$2,150,500	
				15% Engr. & Cont.	322,575	
				TOTAL	$2,473,075	

TABLE IV

MANPOWER SUMMARY

TOTALS BY SHIFT

	Shift			
Alloy IN713LC	1	2	3	Total
Direct Hourly	25	22	5	52
Indirect Hourly	19	16	9	44
Salary	18	5	4	27
TOTAL	62	43	18	123

Alloy IN-738				
Direct Hourly	29	26	5	60
Indirect Hourly	19	16	9	44
Salary	18	5	4	27
TOTAL	66	47	18	131

TABLE IV (cont'd.) MANPOWER

	Shifts			
	1	2	3	Total
Pattern Making				
Plastic Mold Operator	3	3	0	6
Pattern Assembly Area	1	1	0	2
Sub Total	4	4	0	8
Shell Material Prep. and Shell Building				
Batch Slurry Operator	1	0	0	1
Refractory Reconditioning Operator (Sand Lab)	1	0	0	1
Production Line Operator Dip and Stucco	1	1	0	2
Inspection	1	1	0	2
Sub Total	4	2	0	6
Shell Drying Burnout & Fire				
Burn Out Furnace Operator	1	1	0	2
Burn Out Furnace Laborer	1	1	0	2
Sub Total	2	2	0	4
Master Melting Operation				
Furnace Crew	3	3	3	9
Mold Teardown and Assembly	1	1	1	3
Technician	1	1	1	3
Sub Total	5	5	5	15
Production Melting and Casting				
Master Furnace Operator	1	1	0	2
Furnace Helpers	2	2	0	4
Sub Total	3	3	0	6
Cooling and Shakeout				
Operator	1	1	0	2
Laborer	1	1	0	2
Sub Total	2	2	0	4

TABLE IV (cont'd.)

	Shifts			
	1	2	3	Total
Finishing				
Cutoff Machine Operators	2	2	0	4
Inspection	1	1	0	2
Packaging	1	1	0	2
Shipping	1	0	0	1
Sub Total	5	4	0	9
TOTAL	25	22	5	52
Cleaning and Heat Treatment (Optional-Use with IN-738 Alloy Only)				
Heat Treatment Operator	2	2	2	6
Helper	2	2	2	6
Sub Total	4	4	4	12

MISCELLANEOUS MANPOWER

	Shifts			
	1	2	3	Total
Maintenance				
Melting	1	1	3	5
Production Furnace	1	1	3	5
Pattern Room and Shell Room	2	2	0	4
General (Incl die repair)	4	3	2	9
Sub Total	8	7	8	23
Miscellaneous				
Met. Lab. and Sand Lab.	1	1	1	3
Quality Control	2	2	0	4
Foundry Clerk	1	1	0	2
Production Clerk	1	0	0	1
Relief	2	2	0	4
Truck Operators	1	1	0	2
Nurse	1	1	0	2
Stores	1	1	0	2
Shipping	1	0	0	1
Sub Total	11	9	1	21
TOTAL	19	16	9	44

TABLE IV (cont'd.) **SUPERVISION**

	Shifts			
	1	2	3	Total
Manager	1	0	0	1
Production Superintendent	1	0	0	1
General Foreman	1	0	0	1
Metallurgist	1	0	0	1
Chemist	1	0	0	1
Plant Engineer	1	0	0	1
Maintenance Superintendent	1	0	0	1
Maintenance Foreman	1	1	1	3
Production Foreman	3	3	2	8
Draftsman	1	0	0	1
Personnel/IR	1	0	0	1
Accounting	1	0	0	1
Secretary	1	0	0	1
Inventory	1	0	0	1
Security	2	1	1	4
Sub Total	18	5	4	27
TOTAL	18	5	4	27

Turbine Wheel Cost

The following is the summary of costs and resultant per wheel cost:

Alloy Cost - Ingot	= $1.89/pound
Pattern, Shell & Production Melt Cost*	= $0.13/pound
	= $2.02/pound
Material Cost per Wheel	= 2.7 lbs x $2.02/lb
	= $5.45

The direct annual labor costs are as follows:

52 men x 2080 hr./year	
x $7.50 (includes 50%	
fringe benefits)	= $811,200.00

Therefore the direct labor cost to produce 2,000,000 turbine wheels per year is $0.41 per wheel.

The overhead for the production of the 2,000,000 wheels annually consists of indirect labor (hourly and salary) and capital equipment building and grounds as follows:

*Total of $0.03 Polystyrene/wax patterns, $0.05 for refractory shell and $0.05 for melting costs (includes power, water & crucible refractory, etc.) in the production furnace.

			Annual
1.	Capitalization & Depreciation Schedule		
	a.	Equipment (12 years) $10,378,750 ÷ 12	$ 864,896.00
	b.	Building and Grounds (20 years) $2,649,600 ÷ 20	$ 132,480.00
2.	Labor, Indirect		
	a.	Hourly 44 men x 2080 hr/year x 7.50	$ 686,400.00
	b.	Salary 27 men x 2080 hr/year x 7.50	$ 421,200.00
3.	Miscellaneous Expenses		
	a.	Shipping, packaging & supplies	$ 100,000.00
	b.	Telephone, etc.	14,400.00
	c.	Lease Equip., Professional Services, etc.	19,200.00
	d.	General Maintainence	195,500.00
	e.	General Utilities, etc.	208,500.00
	f.	Property Insurance, Taxes and Related Items	200,000.00
		TOTAL	$ 737,600.00

Thus the annual overhead dollar total is $2,842,576.00 (Incl. items 1,2 & 3). The overhead percentage is therefore

$$\frac{\$2,842,576.00}{811,200.00} = 350\%$$

With a direct labor cost of $0.41 per wheel the labor cost per wheel including overhead is $0.41+(0.41 X 3.50)=$1.85. Adding material to this ($5.45 + $1.85) the final cost is $7.30.

To this cost, utilizing the original manufacturing assumptions of 10 percent for General and Administrative costs and 25 percent for corporate profit.

$7.30 x 1.10 = $8.03
then $8.03 x 1.25 = $10.04

the final O.E.M. selling price per wheel is $10.04 each.

OPTIONAL ALLOY IN-738 SUPPLEMENT

This supplement to the study was initiated to include the cost impact of substituting alloy IN-738 for IN-713LC as the primary casting alloy for automotive turbine wheels.

This alloy is currently reaching production status in aircraft turbine wheels due to its characteristic improvements in elevated temperature properties. This alloy is a vacuum cast, precipitation hardened, nickel base alloy, with excellent high temperature mechanical properties coupled with hot corrosion resistance. A complete summary of both alloy systems may be found in addendum #2.

The fabrication characteristics of the alloy indicate that it would not present substantially different casting problems than would IN-713LC. There are two primary cost areas that would, however, have an influence on the final price structure, these are higher alloy constituent costs and an additional heat treatment operation.

The additions to the process requirements are described as follows:

Optional Heat Treating (Required with IN-738 Alloy)
The heat treatment of the castings will be carried out using current heat material procedures automated where applicable to lower labor costs. Any heat treatment will be carried out in assembly and before the cutoff operation.

The precipitation treatment will be carried out in a horizontal vacuum furnace with multiple chambers to be able to keep the high temperature zone in constant operation.

The castings will be stacked in batches in an appropriate configuration and loaded in the entry lock adjacent to the heating chamber. After the vacuum is balanced with the heating chamber, the inner door will open and the batch charged into the heating chamber. The batch will be precipitation hardened for two hours at 2050°F and when the cycle is complete, moved to the cooling chamber and cooled to approximately 1000°F.

The batch is then charged into an aging furnace (either a batch or continuous unit) and will be aged for a minimum of 12 hours at 1550°F. This furnace/s is intended to be an standard atmosphere unit, however, exothermic generator gas can be used if oxidation would be a problem. After the aging cycle is complete, the batch is allowed to air cool, preferably accelerated using a cooling tunnel of forced air.

The castings are then removed from the batch racks and transferred on a soft conveyor to the cutting lines.

To accomplish the above described heat treat operation additional manpower would be required. The manpower relationships are summarized on page 48.

The alloy constituent summary and resultant raw materials costs are shown on Table V. These costs are represented on Table VI for annual requirements and the per pound cost for master ingot therefore is $2.41 per pound. In addition using the developed prices of the IN-713LC for shell, production melting and pattern at an additional $0.13/lb. The Raw material cost is $2.54 per pound or $6.86 per wheel.
The annual overhead for this supplement develops as follows:

1.	Annual Depreciation-Equipment	$ 971,752.00
2.	Annual Depreciation-	173,850.00
3.	Indirect Labor	686,400.00
4.	Misc. Expense *	737,600.00
5.	Salary	421,300.00
		$2,990,902.00

The direct labor annual cost is $936,000.00. Thus the overhead rate develops at 319.5%.

* See Misc. Expense Page 46

The above figures reflect the total dollar outlay per annum to produce 2,000,000 turbine wheels in IN738.

The direct labor cost therefore is:

$936,000.00 ÷ 2,000,000 wheels or $ .468 per wheel.

The direct labor plus overhead rate therefore is projected as:

.486 + (.468 X 3.195)= $1.98 per wheel or
a labor material ratio of approximately 3:1

Therefore using the previous G&A figure of 10%, and profit of 25% the selling price per wheel develops as:

Material	$6.86
Labor	1.98
Total	$8.84

Plus G&A	$8.84 x 1.10 = $9.72
Plus Profit	$9.72 x 1.25 = $12.15

The O.E.M. selling price for IN-738 turbine wheels is therefore $12.15 each.

TABLE V
MASTER HEAT-VIRGIN MATERIAL COST-IN738

Element	%	Form	Cost/Lb./$	Wt./Ton/Lb.	Cost/Ton/$
C	.15	Powder	.50	3.0	1.50
Cr	16.00	Electronic	1.15	320.0	368.00
Mo	1.75	Pellet	3.70	35.0	129.50
Al	3.40	Pig	0.28	68.0	19.04
Ti	3.40	Sponge/Scrap	1.37	68.0	93.16
Zr	0.10	Ni/Zr (70%)	3.52	2.0	7.04
W	2.60	Pellet	5.85	52.0	304.20
B	0.10	Ni/B (18%B)	3.25	2.0	6.50
Co	0.85	Electrolytic	2.35	17.0	39.95
Ta	1.75	Sheet/Scrap	10.50	35.0	367.50
Cb	8.50	Ni/Cb (50%)	6.51	170.0*	1106.70
Mn	0.20	Pellet/Scrap	4.00	4.0	16.00
S	.01	-	-	-	-
Ni	62.20	Electrolytic or Carbonyl Pellet	1.53	1131.0**	1730.43**
				(113) **	
				2020.0	4189.52

Price Per Lb. = $\frac{\$4189.52}{2020 \text{ Lb.}}$ = $2.074 Lb.

*Yields 170 lbs. of Cb @ 60% Cb/40% Ni. Ni weight transferred to Ni requirement at no cost.

**Includes 113 lbs. of transferred Nickel from Cb/Ni alloy.

TABLE VI

ANNUAL INGOT PRODUCTION-COST SUMMARY

ALLOY IN-738

Description	Wgt/Annual/lbs.	Melt Cost/lb.	Metal Cost/lb.	Annual Cost Total
Required Del. Product	5,400,000	$0.03	$2.07	$11,340,000.00
Revert Metal	1,890,000	0.08*	Transfer	151,200.00
Total Metal Loss	727,000	0.03	2.08	1,526,700.00
Virgin Metal	6,127,000	0.03	2.07	12,866,700.00

ANNUAL INGOT COST-POUND-IN-738

Required Wgt.	5,400,000		2.41**	$13,017,900.00

* Includes Reprocessing Cost + Melting Cost.
** Includes Average Cost for Delivered product, Revert Metal and Total Melt Loss Replacement

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850 Providence Highway
Dedham, Massachusetts 02026

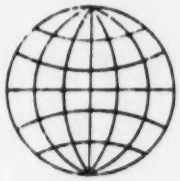
ADDENDUM 1

AUTOMATED INVESTMENT CASTING

IN THE USSR

FOUNDRY MAGAZINE

August 1972



FOREIGN FOUNDRIES . . . . a series

Automated Investment Casting in the USSR

Soviet development of automated investment casting is highly advanced. In one automotive investment foundry, 80% of all operations are automated, including pattern material preparation, slurry preparation, patternmaking, ceramic moldmaking, dewaxing, firing of shells, embedding the shells in backup sand, pouring, cooling, cleaning, and cutoff. As a result of automation like this, up to 1,000 investment cast parts are used in automotive applications.

■ THE SCOPE of application of investment casting in the USSR is wide, particularly in producing parts for automobiles, tractors, airplanes, sewing machines, bicycles, and motorcycles. In the automobile industry alone, as many as 1,000 types of castings are produced by investment casting, many having been switched from drop forging, stamping, or welding.

In 1967, the Gorky Automobile works established an automated investment casting foundry incorporating two production lines. See Fig. 1. Each line can produce 500,000 molds per year in a two-shift operation—or about 2,500 metric tons of castings annually per line. Typical castings produced are shown in Fig. 2.

Eighty percent of all operations are automated. Through use of new technology, plus automation, the moldmaking - casting production cycle has been reduced from 60-70 hr to 24 hr.

Pattern Materials — To reduce pattern shrinkage, pattern material is melted and saturated with air to convert it into an easy-flowing, compressible paste. The micro-sized air bubbles forced into the melted material and later injected into a die cavity offset the natural shrinkage of the material. The process is applicable to any formulation with dripping point up to 80 C (176 F).

Pattern material melted out of molds with hot water is separated easily from the water, due to its different specific gravity, and pumped to the melting unit. It is heated with hot water circulating through piping in its walls and bottom. Return pattern material enters a first compartment where any remaining water and contaminants settle out. Clean pattern material passes over into a second compartment where it is stirred to prevent separation of constituents and to mix in fresh ingredients. Makeup material is melted in a steam-heated tank and filtered before it is added.

From the melting unit, molten pattern material is pumped through a heated pipeline to storage tanks. Pumping is controlled automatically to maintain material at preset levels. In the storage tanks, the pattern material is cooled to the required temperature and flows by gravity through a heated pipe into the paste preparation unit.

There the required amount of air is mixed into the pattern material prior to delivery by pneumatic pumps through heated pipelines to the patternmaking machines. Temperature is controlled to within 1 degree C (less than 2 degrees F).

As shown in Fig. 1, four preparation units serve eight patternmaking machines. The preparation, heating, and pumping units are serviced by a single operator who prepares the equipment for operation, controls the machinery, and monitors process parameters.

Automated Patternmaking — Rotary 10-station machines (Fig. 3) produce patterns automatically with injection cycles of 10, 15, or 20 sec, depending on pattern dimensions and the required cooling time. The injection die is filled under pressure at Station 1. The die then is advanced to Stations 2 through 7 to cool the pattern. At Station 8, the die opens and the pattern is pushed out into a water conveyor, which also serves to cool the material further.

At Station 9, the die cavity is cleaned and lubricated, and at 10 it is closed. All operations are interlocked, and the drive is stopped automatically if a malfunction occurs. The dies are cooled with cold water circulated through channels in both halves of the dies.

Patterns are produced in a cluster around a central hub. When the clusters are assembled into pattern trees, the hubs make up the pattern for the central runner, as shown in Fig. 4. Adoption of standard elements in the running system provides for easy changeover from one type of casting to another. Up to 10 different patterns can be produced simultaneously.

Each injection machine is manned by an operator. The operator cleans and lubricates the injec-

SOVIETS TO LICENSE TECHNOLOGY

The Soviets believe their technology for investment casting is advanced, and they are willing to work with American firms to establish similar investment casting production facilities in the U. S. Technology Associates Inc., Dedham, Mass., a technology transfer consulting firm, is handling the project in the U. S.

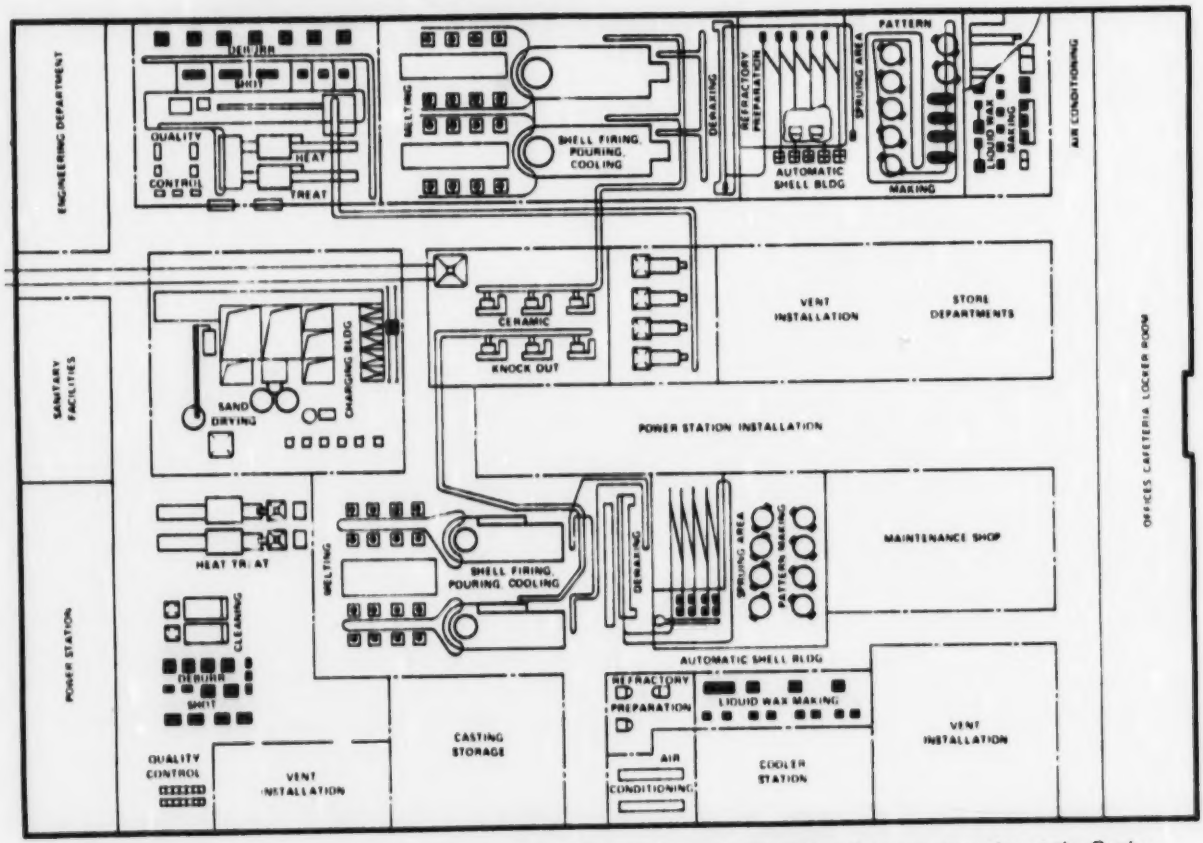


Fig. 1–Two automated investment casting lines are operating at the Gorky Automobile Works. The first production line, bottom of layout, was placed in a former machine shop. Second line was installed later.

tion molds as needed.

Size of the automatic injection die is 240 x 240 mm (9.4 x 9.4 in.). Usable pattern cluster diameter is about 220 mm (about 8.5 in.). The closing stroke is 170 mm (6.7 in.). Cycle time depends on the size of the casting, with 10 sec typically used for castings weighing up to 70 g (2.5 oz) and 15 sec for castings weighing more than 70 g. Thus output per machine is 360 clusters per hour for the 10-sec cycle; 240 for the 15-sec cycle. Time required for readjustment to a new type pattern is 25-30 min.

As noted, the pattern cluster is discharged into a water conveyor, which carries it to the assembly area. A pouring basin pattern first is put on a holder attached to a conveyor chain. Then the several clusters are added with the aid of a holding jig. The assembled set is locked on the holder with a metal cap that is coated with pattern composition. Two workers assemble patterns in a temperature-controlled room.

Slurry Production — Preparation of the slurry, under supervision of one operator, begins with the automatic metering and mixing of

Fig. 2–Typical Soviet investment castings. Rocker arm casting, lower left, is about 3 in. long.

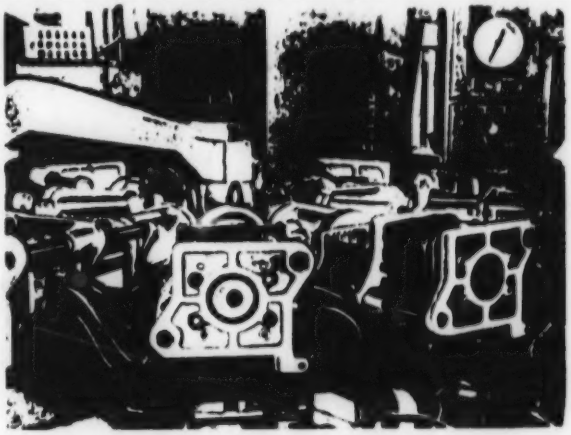


Fig. 3–Rotary 10-station machine produces patterns automatically. When necessary, all 10 dies can be different. Die changing time is about ½ hr.

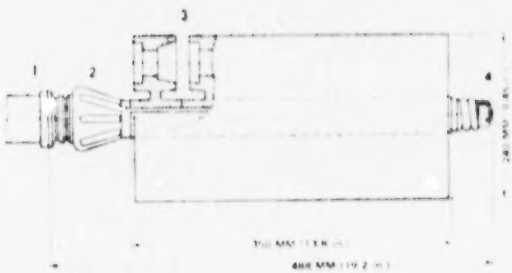


Fig. 4–Standardized pattern assembly shows the riser (1), basin (2), pattern clusters on central hubs (3), and the metal cap that locks the assembly on the holder (4).

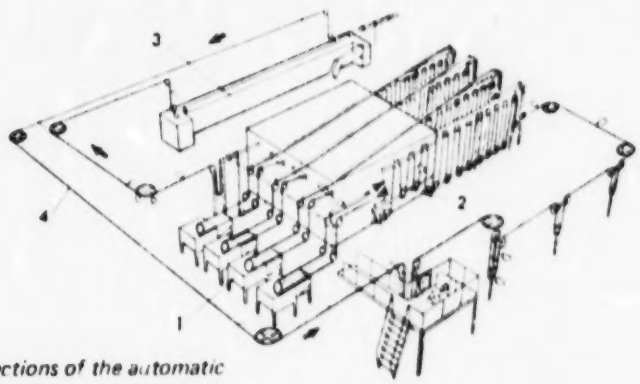


Fig. 5–Main sections of the automatic system for making shell molds are the automatic coating and sprinkling machine (1), drying chamber (2), bath for melting out pattern material (3), and the conveyor (4) that ties the system together.

ethyl silicate and acidulated water in a small tank. From there the hydrolyzed silicate is dispensed into the main mixing tank. Quartz powder is fed into this tank by an automatic weighing feeder belt. The ingredients are mixed vigorously, and finished slurry is delivered continuously through an overflow pipe at the rate of 180 kg (400 lb) per hour. The system also permits batch operation when needed. Prepared slurry is dispensed into storage tanks, then delivered to the dip-coating baths, where the proper level is maintained automatically.

Shell Molding—Slurry in the dip-coating bath is stirred continuously to prevent settling of solid materials.

Assembled pattern trees are delivered by conveyor to the first dip-coating and stuccoing unit (Fig. 5). After the assembly has been dipped into the slurry, it passes under a curtain of sand and into a drying chamber where the slurry-stucco coating is dried in air and in an ammonia atmosphere. Evaporation of ammonia from the ceramic coating is done in a separate section of the drying chamber. The pattern trees then are delivered to a second dip-coating unit.

Spill sand from the stuccoing operation is returned by elevator to the overhead chute for further use. Sand is replenished by a pneumatic conveyor. The process just described is repeated four times in the system diagrammed in Fig. 5. Dipping and stuccoing units are maintained by one operator.

Completed shell molds are loaded onto fixtures hung from a monorail chain conveyor that carries the molds through a hot-water bath for pattern removal. As the dewaxed molds leave this operation, a worker removes them from the conveyor, inspects them, and sorts them according to grade of steel to be poured. One operator controls the chain conveyor, drying chambers, and dewaxing baths.

The entire moldmaking area is air conditioned to maintain required temperature and humidity. Automation of the shell-making operation has eliminated manual labor at the dip-coating and stuccoing areas in the atmosphere of acetone and the silicate vapors with suspended quartz powder.

Firing and Pouring—The shell molds are mounted on conveyor hangers, as shown in Fig. 6, with each hanger accepting two small-diameter molds or a single mold of larger diameter. The pouring basin is covered with a removable cap to keep sand from entering the mold and to fix the mold to the hanger.

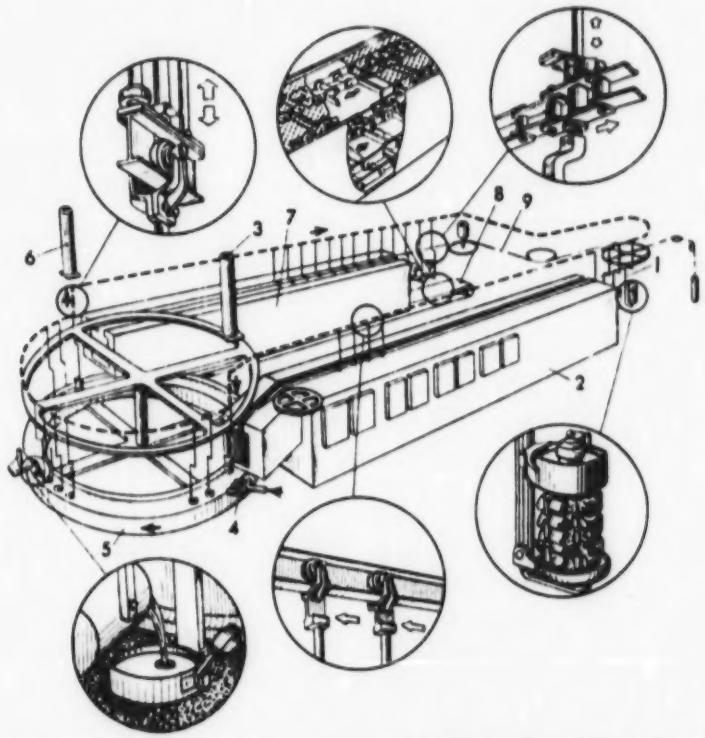


Fig. 6—Shell molds are placed on a hanger (1) before entering the gas-fired furnace (2). As molds exit the furnace, they are lowered by a pneumatic hoist (3) into a bed of sand heated by manifolds (4). They move with the rotary bed (5) to the pouring station and then to the unloading station, where a pneumatic hoist (6) lifts them out of the sand. Molds then pass through a cooling chamber (7). A belt conveyor (8) catches spill refractory, and a trolley conveyor (9) moves molds through the system.

The mold passes into the furnace for firing at 900 C (about 1,650 F). The hanger follows a slit in the roof of the furnace so that the conveyor chain, hanger carrier, and track are outside the hot zone. Exhaust ventilation is provided along the entire slit in the roof.

On leaving the oven, the fired shells are immersed in a bed of sand, fluidized by hot air, at the rotary pouring machine. The chain conveyor drives the trough in synchronization through a sprocket.

Shells leave the fluidized zone firmly embedded in the backup sand. They enter a 6-m (20 ft) pouring zone that takes up half the circumference of the turntable. Molds are poured from shank ladles of 80-kg capacity (about 175 lb). Steel melts are prepared in 160-kg (about 350-lb) induction furnaces.

The turntable continues its rotation, and the poured molds cool to about 1,200 C (about 2,200 F), after which they are lifted out by an air hoist. They then are moved by chain conveyor to a water-spray cooling chamber. On leaving the cooling chamber, the poured molds are removed from the conveyor hangers, and the latter are returned to the shell assembly station.

Shakeout, Cutoff—Poured shells are placed manually on a shuttle conveyor for movement to a vibrator that shakes shell material from the sprue of castings. The shuttle carries the sprue of castings to a cutoff unit that consists of an annular cutting die mounted in a press. Castings fall to a container or a belt conveyor, and the riser is ejected. The press stroke may be pulsating to improve the cutoff action.

That approach to cutoff was made possible through adoption of a feeding system of standard dimensions. Yield was sacrificed in some instances for the sake of automating the cutoff operation.

Final Cleaning — Complete removal of ceramic from the castings is achieved by an alkaline bath and hot-water rinse in a two-compartment, rotating barrel at the rate of 450 kg (about 990 lb) of castings per hour. A vibrating feeder delivers the castings to the barrel, and cycling through the baths is automatic. Cleaned and washed castings are delivered to furnaces for normalizing treatment under a protective atmosphere to prevent scaling and decarburization.

Following normalization, the steel castings have a fine-grained, homogeneous structure of pearlite and ferrite. The decarburized zone is .3 to .35 mm (.12 to .14 in.) deep.

Process Control—Control of the entire system is from a central office. Control consists of the following functions:

- Remote automatic registration of the number of pattern assemblies and shells made (usable, rejected, fired) and of cutoff casting assemblies.
- Remote automatic registration of shells in storage.
- Remote semiautomatic registration of the number of castings by type sent to storage and delivered from storage as finished products.
- Automatic recording of all data on report form by automatic electric typewriter.
- Remote automatic transmission of all report data to the plant's computer center for preparing and issuing to the shop detailed schedules for starting up, production output, and for processing reports on fulfilment of the shop plan.
- Signaling the operating condition of basic equipment.
- Automatic selective registration of operating and downtime of basic equipment.
- Remote automatic monitoring of availability of basic materials.
- Telephone control intercom within shop.
- Radio communication within shop for production purposes.
- Transmission of rapid chemical analyses of metal from laboratory to steel-melting department.

ADDENDUM 2

ALLOY SUMMARIES

713LC/IN-738

INTERNATIONAL NICKEL

ALLOY 713LC
LOW CARBON ALLOY 713C

The low carbon modification of alloy 713C* was developed by C. G. Bieber at the Bayonne Research Laboratory of The International Nickel Company, Inc. to combine the good stress rupture properties of the base material with excellent room temperature ductility and strength. The combination of these properties becomes highly desirable in such applications as the integrally cast wheel. The highly stressed, heavy hub section of the wheel remains at a relatively low temperature while the thin leading and trailing edges of the blades must withstand cyclic temperatures up to 1800 F, depending upon the engine. Recent evidence has shown that alloy 713LC produced with a low iron content, i.e. less than .50%, has superior mechanical properties to heats containing high iron, i.e. greater than 1.20%. Data presented here will cover material manufactured to the recommended composition listed below as well as alloy containing high iron as originally produced.

Composition – weight per cent

The nominal composition and recommended range to which the alloy is produced are shown in the tabulation below:

Element	Nominal	Range
Carbon	0.05	0.03 – 0.07
Chromium	12.00	11.00 – 13.00
Molybdenum	4.50	3.80 – 5.20
Columbium + Tantalum	2.00	1.50 – 2.50
Aluminum	5.90	5.50 – 6.50
Titanium	0.60	0.40 – 1.00
Boron	0.01	0.005 – 0.015
Zirconium	0.10	0.05 – –.15
Silicon	LAP†	0.50 max.
Manganese	LAP	0.25 max.
Iron	LAP	0.50 max.
Copper	LAP	0.50 max.
Sulfur	LAP	0.015 max.
Nickel	Balance	Balance

Effect of Carbon Content

Figure 1 illustrates the effect of carbon content on the room temperature tensile properties, while Figure 2 shows its relationship to stress rupture properties. The data presented include results from both laboratory and commercial melts. The apparent increase in stress rupture properties at "zero" carbon over the values at 0.02% carbon does not reflect the true variation with carbon content, but rather represents all laboratory heats produced with NiCb versus all the commercial melts produced with FeCb.

* U.S. Patent #2,570,193, produced under license from The International Nickel Company, Inc.

† Low as possible

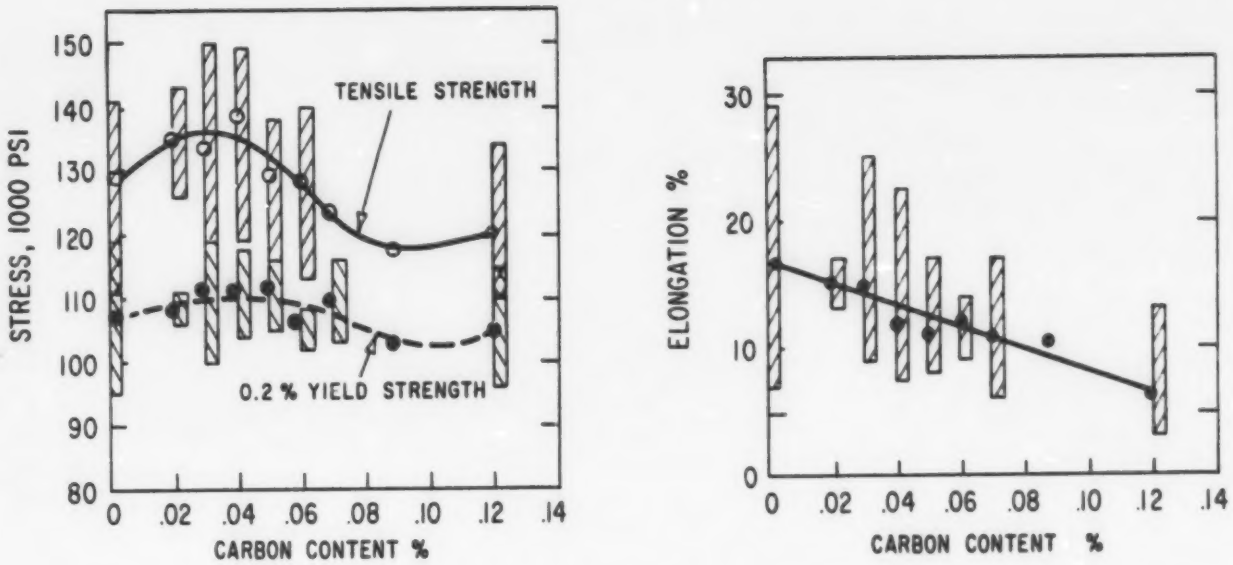


Figure 1. Room Temperature Tensile Properties vs. Carbon Content of As Cast, Vacuum Melted, Vacuum Cast Alloy 713LC.

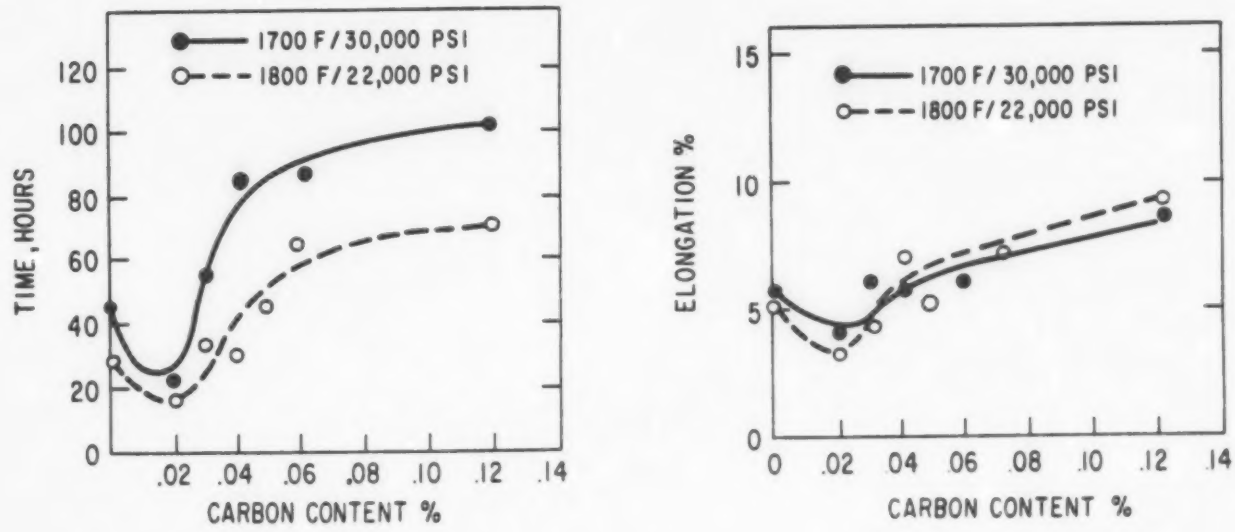


Figure 2. Stress Rupture Properties vs. Carbon Content of As Cast, Vacuum Melted, Vacuum Cast Alloy 713LC.

Physical Properties – Low Fe Material

Density

.289 lbs/cu in (8.01 g/cu cm)

Melting Range (estimated)

2350-2410 F

Oxidation Resistance (See Figure 3)

Samples were given cyclic exposure by heating in air to 1900 F for 16 hours and cooling for 8 hours.

Time, hrs.	Wt. Change, % 713LC	IN-100	Time, hrs.	Wt. Change, % 713LC	IN-100
16	+ 0.17	+ .02	128	– 0.14	– .44
32	+ 0.23	– .07	144	– 0.07	– .48
48	+ 0.29	– .14	160		
64	+ 0.15	– .24	176	– 0.08	– .62
80	+ 0.04	– .24	192		
96	+ 0.05	– .28	208	– 0.08	– .82
112	0.0	– .38			

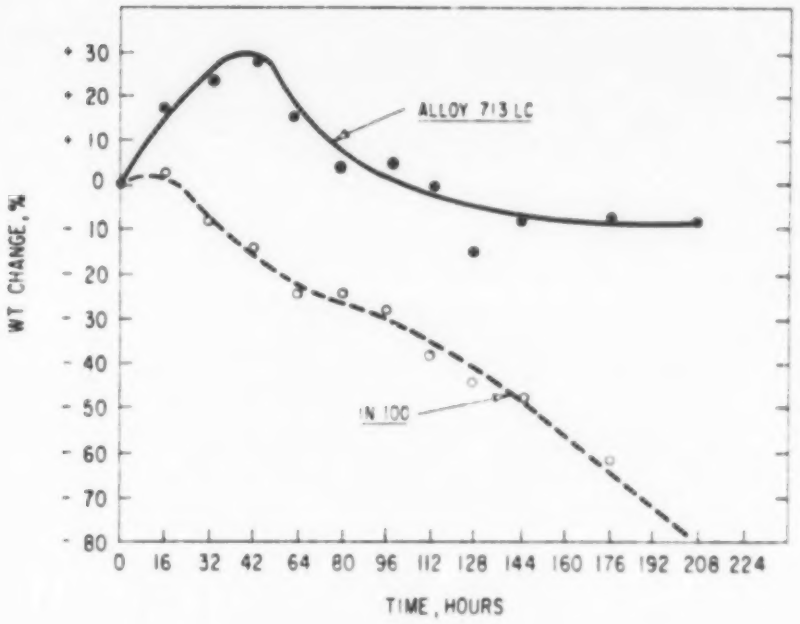


Figure 3. Oxidation Resistance of Alloy 713LC – Cyclic Test 16 Hours At 1900 F, Cool In Air For 8 Hours.

Mechanical Properties – Low Fe Material (< .50%)

Tensile Properties – Cast to Size Bars (See Figure 4)

Test Temp. F	0.2% Yield Strength psi	Tensile Strength psi	Elong. %	Reduction of Area %
70	109,000	130,000	15.3	20.9
1200	113,900	157,000	11.0	11.0
1500	99,000	123,000	15.0	17.0
1700	66,900	94,200	6.0	12.0

Tensile Properties – Machined from hub of wheel

Test Temp. F	0.2% Yield Strength psi	Tensile Strength psi	Elong. %	Reduction of Area %
70	96,200	101,000	17.0	20.0
70*	121,400	140,500	10.5	17.5

*Solution Treated 2150 F – 2 hrs. – AC

Stress Rupture Properties – Cast to Size Bars (See Figure 5 and 6)

Test Temp. F	Stress psi	Life hrs.	Elong. %	No. of Tests
1350	90,000	201.0	4.0	2
1400	85,000	81.7	3.1	2
1500	60,000	131.5	10.7	1
1500	40,000	3023.1	10.7	1
1500	40,000	3500	(3.6)*	1
1700	30,000	66.6	8.5	10
1700	20,000	1686.2	5.5	1
1800	22,000	62.1	7.2	66
1800	15,000	930.0	7.6	2

*Test stopped after 3500 hours. Bar had 3.6% creep. Room temperature tensile test on the bar indicated the following:

Test Temp. F	0.2% Yield Strength psi	Tensile Strength psi	Elong. %	Reduction of Area %
70	88,500	110,800	10.0	17.5

Effect of Iron Content on Stress Rupture Properties

Increasing iron decreases the high temperature strength of this alloy by lowering the solutioning temperature of the gamma prime phase Ni_3 (Al, Ti). It has been shown that the elevated temperature stress rupture strength of alloy 713C and a similar alloy is adversely affected by the addition of iron to master heats made with pure columbium. The following data indicate the effect of iron on several laboratory melts of alloy 713LC produced with the columbium addition being made in the form of ferrocolumbium in one case and nickel columbium in the other.

Test Conditions: 1800 F – 22,000 psi

	NiCb (approx. .15% Fe)	FeCb (approx. 1.50% Fe)
No. of Melts	12	7
Average Life, hrs.	65.7	42.8
Range of Life, hrs.	37.3 – 101.9	29.4 – 64.2
Average Elong. %	8.2	6.8
Range of Elong. %	4.2 – 10.6	3.5 – 10.6

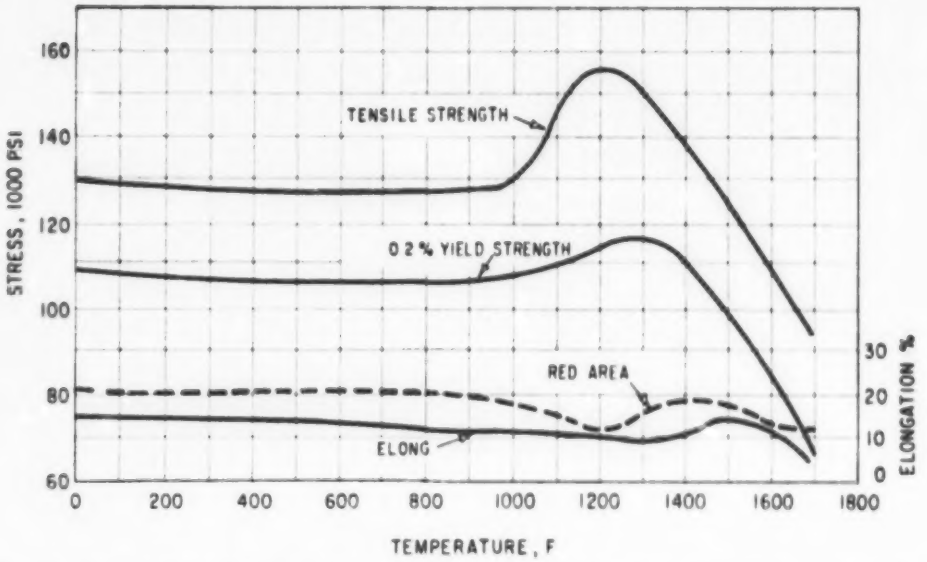


Figure 4. Typical Tensile Properties of As Cast, Vacuum Melted, Vacuum Cast Alloy 713LC. (Low Fe Material)

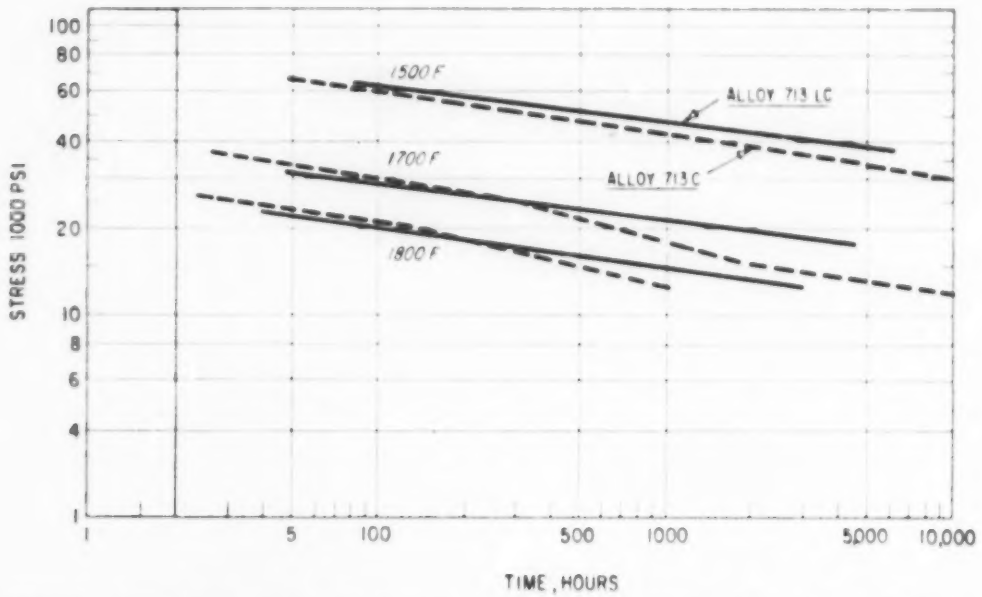


Figure 5. Stress Rupture Data On As Cast, Vacuum Melted, Vacuum Cast Alloy 713LC. (Low Fe Material)

Mechanical Properties – High Fe Material (Approx. 1.50%)

Tensile Properties – Cast to Size Bars (See Figure 7)

Test Temp. F	0.2% Yield Strength psi	Tensile Strength psi	Elong. %	Reduction of Area %
70	109,400	133,100	13.2	20.5
1000	108,400	132,200	8.0	19.5
1200	109,900	138,100	6.0	14.5
1350	111,100	145,300	8.0	21.0
1500	87,200	124,500	12.0	17.0
1700	55,700	88,400	9.0	13.5

Tensile Properties – Machined from hub of wheel

Test Temp. F	0.2% Yield Strength psi	Tensile Strength psi	Elong. %
70	89,200	94,300	16.0
70*	101,500	112,800	18.2
1350	92,600	108,100	11

*Solution Treated 2150 F – 2 hrs. – AC

Stress Rupture Properties – Cast to Size Bars (See Figure 6)

Test Temp. F	Stress psi	Life hrs.	Elong. %	Reduction of Area %
1350	90,000	64.6	4.0	11.0
1500	60,000	68.0	5.3	14.3
1700	30,000	57.8	4.0	5.5
1800	22,000	42.8	6.8	13.3

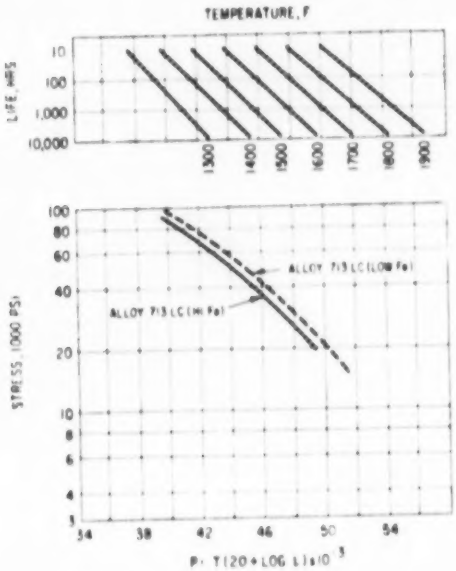


Figure 6. Larson Miller Stress Rupture Parameter Curve For Alloy 713LC.

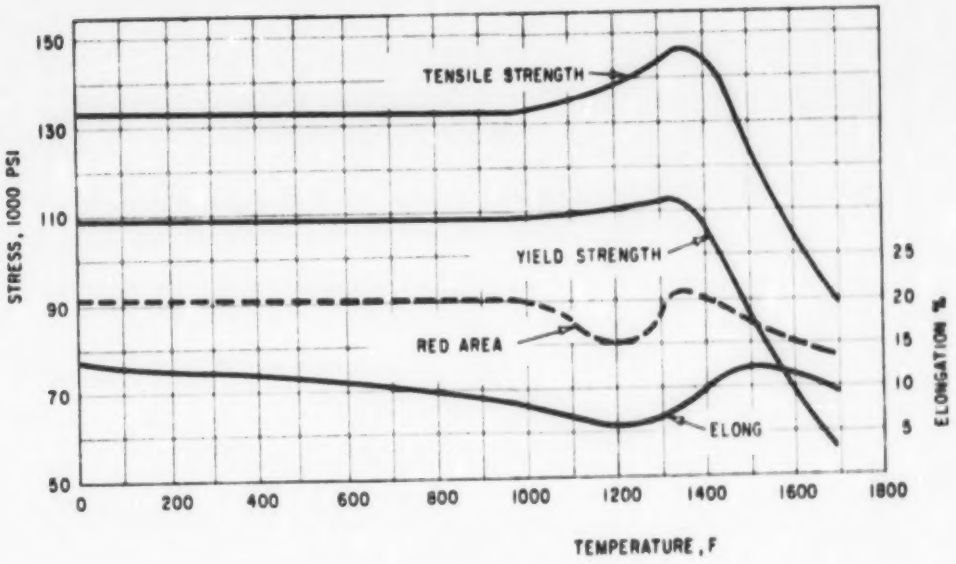


Figure 7. Typical Tensile Properties of As Cast Vacuum Melted Vacuum Cast Alloy 713LC. (High Fe Material)

Dynamic Modulus of Elasticity (See Figure 8)

Test Temp. F	Dynamic Modulus psi	Test Temp. F	Dynamic Modulus psi
70	28.55×10^6	1000	24.97×10^6
200	28.10	1200	24.00
400	27.31	1400	23.09
600	26.59	1600	21.61
800	25.84	1800	19.72

Fatigue Data

Reversed stress axial fatigue tests on machined bars in the as cast condition indicated the following endurance limits at 10^8 cycles:

Test Temp. F	Grain Size	Speed cpm	Endurance Limit, psi (10^8 Cycles, A ave, K_t = 1.0)
1200	3/16"–1/4"	12,500	26,000
1500	3/16"–1/4"	11,500	25,000

As with the standard alloy 713C, the low carbon version exhibited a cleavage type of fracture at 1200 F.

Effect of Casting Temperature

Castings of alloy 713LC are normally poured at temperatures of approximately 3000 F to ensure soundness, fill and optimum mechanical properties. The lower carbon content of this material requires closer control of casting temperatures due to its marked influence on properties as indicated by the following data:

Effect of Casting Temperature - High Fe Material (Approx. 1.50%)

Room Temperature Tensile Data

Casting Temp. F	0.2% Yield Strength psi	Tensile Strength psi	Elong. %	Reduction of Area %
	Condition: 1900 F Mold, Non-inoculated			
P* + 200	104,200	126,800	8.5	11.2
P + 590	110,500	121,600	15.3	18.2
	Condition: 1650 F Mold, Non-inoculated			
P + 200	107,200	133,800	12.8	18.1
P + 500	105,700	127,500	17.2	23.2
	Condition: 1600 F Mold, Non-inoculated			
P + 250	117,000	138,000	9.0	12.0
P + 550	108,300	130,800	16.0	24.0
	Condition: 1400 F Mold, Non-inoculated			
P + 350	114,500	130,000	7.0	8.8
P + 550	108,300	130,800	16.0	24.0

*P = Plateau = Liquidus

Stress Rupture Data

Casting Temp. F	1700 F/30,000 psi Hrs.	Elong.	1800 F/22,000 psi Hrs.	Elong.
P + 250	30.3	2.7	17.2	2.7
P + 350	56.8	4.0	32.3	4.0
P + 550	95.8	6.7	42.8	6.8

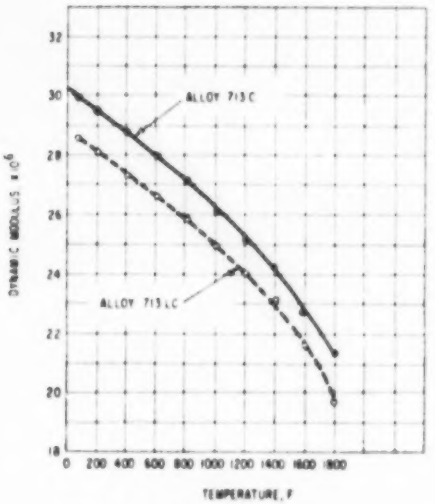


Figure 8. Dynamic Modulus of Elasticity of As Cast, Vacuum Melted, Vacuum Cast Alloy 713C & Alloy 713LC. (High Fe)

IN-738
Preliminary Data

INTRODUCTION

IN-738* is a vacuum cast, precipitation hardened, nickel-base alloy possessing excellent high temperature creep-rupture strength combined with hot corrosion resistance superior to that of many present day high strength superalloys of lower chromium content. It is designed to provide the turbine industry with an alloy which will have good creep strength up to 1700-1800F combined with ability to withstand long time exposure to the hot corrosive environments associated with the engine.

IN-738 exhibits tensile properties superior to and elevated temperature stress-rupture properties comparable to those of the widely used alloy 713C, along with substantially better sulfidation resistance.

Three 2500 lb. semi-commercial heats of IN-738 have been melted to date. Data reported herein were obtained with material from those heats.

COMPOSITION – Weight Per Cent

Element	Nominal	Range
Carbon	0.17	0.15 – 0.20
Cobalt	8.50	8.00 – 9.00
Chromium	16.00	15.70 – 16.30
Molybdenum	1.75	1.50 – 2.00
Tungsten	2.60	2.40 – 2.80
Tantalum	1.75	1.50 – 2.00
Columbium	.90	.60 – 1.10
Aluminum	3.40	3.20 – 3.70
Titanium	3.40	3.20 – 3.70
Aluminum + Titanium	6.80	6.50 – 7.20
Boron	.01	.005 – .015
Zirconium	.10	.05 – .15
Iron	LAP **	.50 max.
Manganese	LAP	.20 max.
Silicon	LAP	.30 max.
Sulfur	LAP	.015 max.
Nickel	Balance (60)	Balance

** Low as possible

HEAT TREATMENT

This alloy achieves the best combination of mechanical properties after the following heat treatment: 2050F/2 hr/AC + 1550F/24 hr/AC. All properties in this bulletin were obtained with material given this treatment.

* Patent pending.

MINIMUM MECHANICAL PROPERTIES

No property specification has yet been written for IN-738, however, based on material produced to date, the alloy appears capable of at least meeting the stress rupture property levels usually specified for alloy 713C. The tensile properties appear to offer a significant advantage over alloy 713C.

PHYSICAL PROPERTIES

DENSITY – 0.293 lb/in.^{3} (8.11 g/cm^3)

MELTING RANGE – 2250 – 2400F (1232–1315C)

STABILITY – While long time elevated temperature stability can be demonstrated only by long time exposure, a mathematical analysis based on electron vacancy concentration (see Appendix I) is useful in indicating the susceptibility of an alloy to form sigma. The electron vacancy number, N_V, of IN-738 is 2.28. To ensure stability in this alloy, it is recommended that the N_V should not exceed 2.36. In the material produced to date, no deleterious intermetallic phase precipitation has been observed in heat treated material even after 4,000 hr. exposure at 1500F under a stress of 40,000 psi.

THERMAL EXPANSION *(See Figure 1)*

	Thermal Expansion Data for IN-738, Heat Treated 2050F/2 hrs/AC + 1550F/2 hrs/AC	
Temperature (F)	Mean Coefficient of Expansion from 70F to Indicated Temp.	Instantaneous Coefficient of Expansion at Temperature
70		6.2 x 10^{-6} °F
200	6.45 x 10^{-6} °F	6.7
400	6.75	7.4
600	7.15	8.0
800	7.55	8.65
1000	7.75	9.01
1200	8.05	9.1
1400	8.25	10.15
1600	8.55	10.75
1800	8.85	11.6

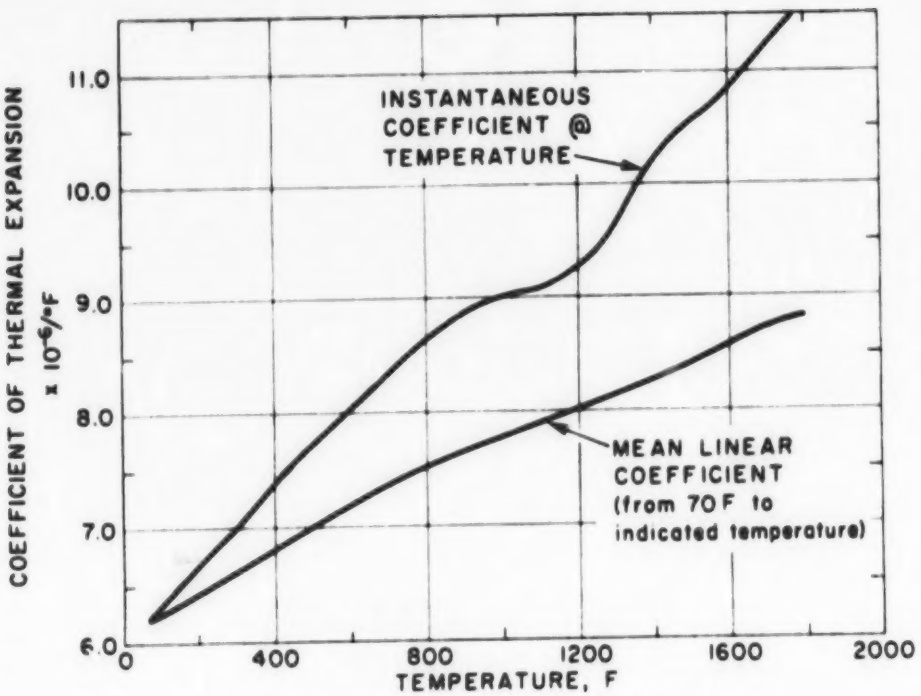


Figure 1. Thermal Expansivity of IN-738.

CHEMICAL PROPERTIES

A. OXIDATION

1. Static Test – 1000 hr., still air

Alloy	Weight Change	
	1800F	2000F
713C	+ 0.6 mg/cm²	+ 29 mg/cm²
IN-738	-16	-102
Udimet 500 (cast)	-22	-328
Udimet 700	- 8	

2. Cyclic Test – Samples were given a cyclic exposure by heating in air at 1800F for 22 hr. and then cooling to RT for 2 hr.

Alloy	Wt. Loss in 1000 Hr.
713C	0.7 mg/cm²
IN-738	14 mg/cm²

B. SULFIDATION

IN-738 has been evaluated in crucible, rig and engine tests in comparison with a number of other alloys. The crucible tests generally consisted of immersion of 1/4" x 1/4" x 1" rectangular samples in a molten mixture of salts followed by descaling operations to determine sample weight loss. The rig tests were performed generally by rotating samples of pin-shapes or airfoil shapes in a combustion stream of fuel containing sulfur. Intermittent cooling cycles were employed to simulate engine operation. During the heating portion of the cycle, salts and/or alkaline metal particles were injected into the stream as detailed in the following tabulation.

The test results obtained are shown below:

1. Crucible Test, 10% NaCl/90% Na_2SO_4 – 1700F

Alloy	Time, Hr.	Remarks
Alloy 713C	2 - 4	Destroyed
Udimet 500 (cast)	40 - 100	Gross Attack
IN - 738	250 - 300	Slight Attack

2. Crucible Test (controlled replacement of salt) –1650F –300 Hr.

Alloy	10% NaCl/90% Na_2SO_4 Wt. Loss, mg/cm^2	25% NaCl/75% Na_2SO_4 Wt. Loss, mg/cm^2
Udimet 500 (cast)	6	16
IN - 738	7	14

3. 1000 Hr. Cyclic Rig Test – 1600F – Diesel Fuel (1% Sulfur) Air/Fuel Ratio: 30/1, 5 ppm sea salt

Alloy	Surface Loss, mg	Max. Penetration, mil.
IN - 738	3.3	19
Alloy 713C	38 – 130+ **	60 – 130+ **
Udimet 500 (wrought)	1.7 – 3.8	12 – 13

4. 1000 Hr. Cyclic Rig Test – 1800F – Diesel Fuel (1% Sulfur) Air/Fuel Ratio: 30/1, 5 ppm sea salt

Alloy	Surface Loss, mg	Max. Penetration, mil.
IN - 738	3.1	15
Alloy 713C	130+ **	130+ **
Udimet 500 (wrought)	3.5	21
Udimet 500 (cast)	8.8	36

** Specimen consumed

5. Sulfidation Cyclic Rig Test (150 Hr.) – JP-5R Fuel, 3.5 ppm salt, about 17/1 Air/Fuel Ratio

	Peak Temperature	
Alloy	1550F Wt. Loss, gms.	1750F Wt. Loss, gms.
IN - 738	2.1	4.0
Alloy 713C	5.5	7.1
Udimet 700	4.0	7.9

6. Sulfidation Cyclic Rig Test (173 Hr.) – JP-5R Fuel, 3.5 ppm salt, about 17/1 Air/Fuel Ratio

Cycle of 1550F/3 min. – 1850F/2 min. – cooled 2 min.

Alloy	Wt. Loss, gms.
B1900	6.8
IN - 738	2.5
MDL 20	3.0
Mar M421	4.2

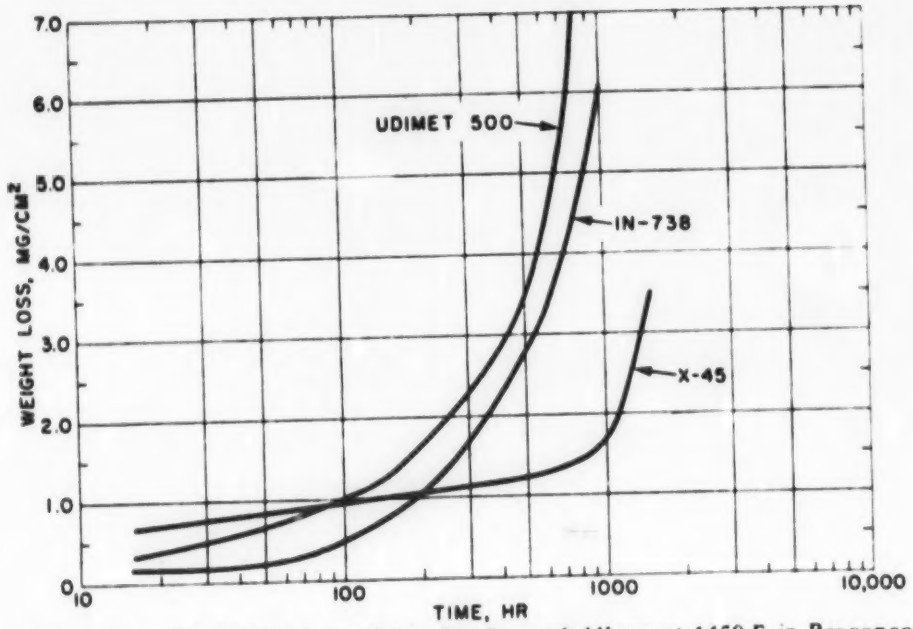


Figure 2. Time VS. Weight Loss Plots For Several Alloys at 1450 F in Presence of Eutectic Na_2SO_4–$MgSO_4$ and 0.15% SO_2.

7. Combustion Chamber Test–Fuel Oil doped with 5 ppm Na, .5 ppm Mg, 1% S–1450F

Alloy	Wt. Loss, % in 50 Hr.
IN-738	.183
X-45	.206
Udimet 500 (wrought)	.143

8. Crucible Test Na_2SO_4, $MgSO_4$ under a gas of .15% SO_2, 2.25 Co, N_2 – 1450F

	Wt. Loss (mg/cm^2) after				
Alloy	32 Hr.	64 Hr.	136 Hr.	250 Hr.	500 Hr.
IN-738	.32	.56	.97	1.4	–
Udimet 500 (cast)	.35	.51	.71	–	3.3
Alloy 713C	8.3	23.	90.	–	–

9. Gas Test–1800F (100 Hr.)–Flowing H_2S and SO_2–rich gas to accelerate corrosion

Alloy	Wt. Loss, mg/cm^2
IN-738	310
Alloy 713C	770
Udimet 700	1440

10. Engine Test – 1780F (45 Hr.) (.75 ppm sea salt) 40 min. cycle (30 min. at 1780F, 10 min. ram cool air)

Alloy	Rating (higher number indicates increasing resistance)
Alloy 713C	1
Mar M246	1.1 times corrosion resistance of 713C
TRW V1A	1.4
235D	1.9
IN-738	6.2
Udimet 710	5.8

The behavior of IN-738 and several other alloys in a eutectic mixture of Na_2SO_4 – $MgSO_4$ at 1450F is shown in *Figure 2*.

MECHANICAL PROPERTIES

TENSILE PROPERTIES

Typical properties obtained on heat treated, cast-to-size test bars (fine grain $\leq$ 1/8" diameter) are as shown below. Property ranges are plotted in Figure 3 in comparison to those of 713C.

Temp. F	0.02% Yield Strength psi	0.2% Yield Strength ksi	Tensile Strength ksi	Elong. %	R.A. %
RT	128	138	159	5.5	5
1350	–	122	145	3	4
1500	–	100	127	3	3
1600	–	80	112	11	13
1700	–	59	81	13	14
1800	–	50	66	10	15

Limited data obtained at R.T. on coarse grain (3/32–5/16" diameter) bars have been essentially the same as shown above.

Stress Rupture Properties *(See Figure 4)*

Rupture properties obtained on heat treated, fine-grain, cast-to-size test bars are as follows:

Temp. F	Number of Tests	Stress psi	Life Hr.	Elong. %	R.A. %
1350	1	100,000	93	13	20
1350	11	90,000	139-291 Avg. 211	4-7 6	8-9 9
1350	1	80,000	452	4	6
1400	1	90,000	89	4	8
1400	2	85,000	130-155	6	–
1450	1	60,000	976	4	5
1500	1	70,000	29	14	17
1500	1	55,000	261	11	14
1500	4	40,000	2794-3947 Avg. 3205	4-6 5	4-8 6
1600	2	40,000	312-430	9	13
1700	1	35,000	29	15	17
1700	6	33,000	97-109 Avg. 104	6-11 8	13 13
1700	1	26,000	190	14	–
1800	1	25,000	55	6	–
1800	1	24,000	65	–	–
1800	19	22,000	39-96 Avg. 78	12-20 15	19-25 23
1800	1	18,000	116	24	27
1800	1	15,000	269	–	–
1825	1	16,000	148	6	14

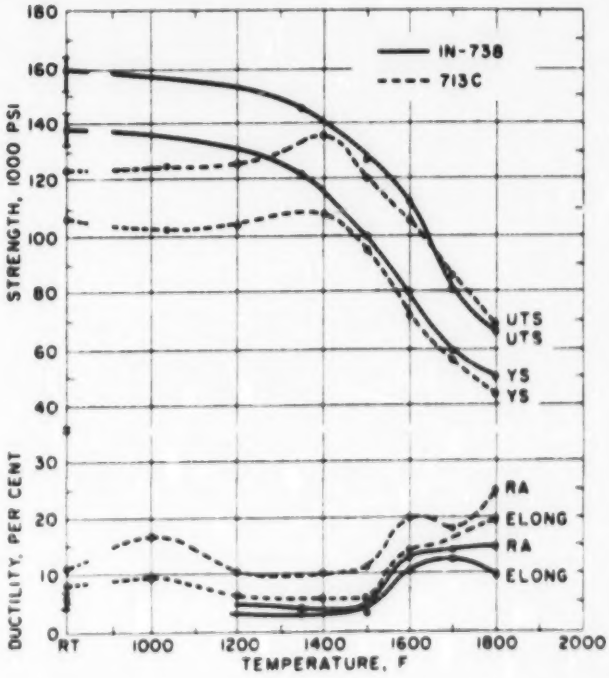


Figure 3. Typical Tensile Properties of IN-738 Compared to those of 713C.

Limited rupture data on coarse grain (1/4") cast-to-size bars are as follows:

Temp. F	Number of Tests	Stress psi	Life Hr.	Elong. %	R.A. %
1350	2	90,000	216	4.5-6	8-11
1350	1	88,000	224	9	12
1500	1	70,000	29	10	12
1500	1	55,000	269	8	10
1700	1	35,000	41	11	16
1700	2	33,000	52-116	6-10	12-17
1800	3	29,000	9- 16 Avg. 14	15 15	18-32 27
1800	4	22,000	30 -95 Avg. 66	6-16 12	17-30 23
1800	1	20,000	128	10	27
1800	1	18,000	132	13	25

A Larsen - Miller parameter plot of the above data is shown in *Figure 5.* Data on 713C and IN - 100 are shown for comparison.

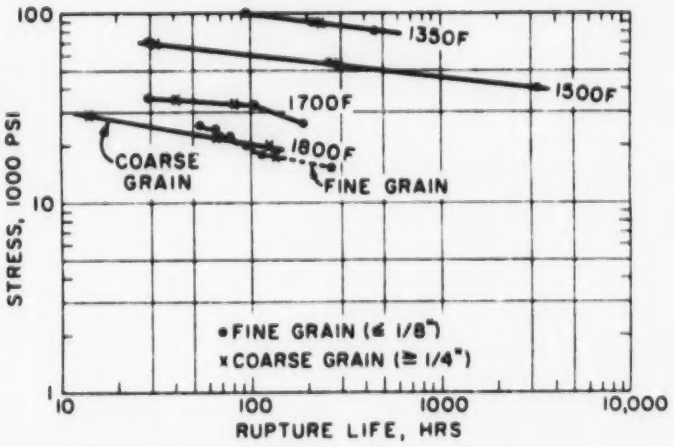


Figure 4. Stress Rupture Properties of Cast-to-Size Bars of IN-738.

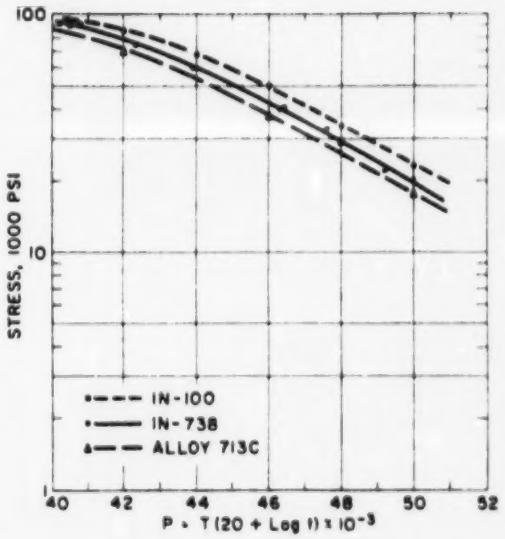


Figure 5. Larsen-Miller Stress Rupture Parameter Plot Comparing IN-738, IN-100 and 713C.

IMPACT PROPERTIES

Unnotched Charpy impact value (ft.-lb.) of samples tested at R.T. after various elevated temperature exposures are as follows:

Grain Size	Impact Value Prior to Exposure	Room Temperature Impact Value After Exposure at 1200F		1500F		1700F	
		500 hr.	1000 hr.	500 hr.	1000 hr.	500 hr.	1000 hr.
Fine $\leq$ (1/8")	56	44	30	20	13	14	10
Coarse $\geq$ (1/4")	37	54	38	20	16	17	14

THERMAL FATIGUE RESISTANCE

The thermal fatigue resistance of IN-738 and of several other cast alloys was determined using a fluidized bed for heat transfer. This method involved alternate 2 minute immersion of 1-5/8" diameter tapered disc specimens, with 0.010 in. edge radius, in hot and cold beds.

Alloy	Thermal Fatigue Cycles to First Crack Peak Temperature of 1472F (800C)	1652F (900C)	1832F (1000C)
713C	> 1462	107	27
IN-100	> 1372	107	29
IN-738	1790	150	13

APPENDIX I

METHOD FOR CALCULATION OF ELECTRON VACANCY NUMBER

1. Convert the composition from weight per cent to atomic per cent.

2. After long time exposure in the sigma forming temperature range, the MC carbides tend to transform to $M_{23}C_6$.
   a. Assume one-half of the carbon forms MC in the following preferential order TaC, CbC, TiC.
   b. Assume the remaining carbon forms $M_{23}C_6$ with the M comprising 23 atoms of Cr.

3. Assume the boron is tied up as Mo_3B_2.

4. Assume the gamma prime to be $(Ni_{.8}Co_{.2})_3$ (Al, Ti, Ta, Cb)

5. Assume the residual matrix will consist of the atomic per cent minus those atoms tied up in the carbide reaction, boride reaction, and the gamma prime reaction. The total of these remaining atomic percentages gives the atomic concentration in the matrix. Conversion of this on a 100% basis gives the atomic per cent of each element remaining in the matrix. It is this percentage that is used in order to calculate the electron vacancy number.

6. The formula for calculation of the electron vacancy number is as follows:

$$N_V = .66\,Ni + 1.71\,Co + 2.66\,Fe + 4.66\,Cr + 6.66\,Zr + 9.66\,(Mo + W)$$